

DRAFT

**Characterization and Evaluation of
Landfill Leachate**

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INTRODUCTION

This report results from a broad-based effort to collect and review data on landfill leachate. This effort included the following:

- A review of existing scientific literature on landfill leaching processes and the factors that influence leachate generation and characteristics.
- A quantitative analysis of leachate generation rates in landfills managing various types of waste.
- Development of a comprehensive database describing the physical properties and chemical characteristics of leachate from landfills managing various types of waste.
- Detailed case studies describing the operation and environment of example landfills representing the various types included in the characterization database.

The report is organized as follows:

- Section 1 provides information on the mobility of inorganic and organic constituents that may be present in waste, primarily based on review of the scientific literature.
- Section 2 presents the results of the quantitative analysis of the available data on leachate generation rates.
- Section 3 discusses the properties and characteristics of landfill leachate. This discussion includes presentation of summary statistics from the characterization database for various categories of landfill. It further compares these characteristics across landfill types, based on the empirical data and the scientific literature.
- Section 4 summarizes the landfill case studies.
- Section 5 is the bibliography of sources reviewed from the literature.

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1. MOBILITY OF INORGANIC AND ORGANIC CONSTITUENTS

Leachate characteristics are a function of the constituents contained in the disposed wastes and the waste management environment. The mobility of both inorganic and organic constituents is dependent upon many interrelated factors. These factors include most importantly the waste type, waste management unit, and climate of the intended disposal unit. Physical characteristics of the waste type may increase or decrease the mobility of constituents. For example, a cementitious solidified waste is less likely to release toxic constituents because those constituents are bound within the cementitious matrix. On the other hand, a granular waste such as combustion ash residues, may be more likely to release toxic constituents due to increased surface area and a matrix that allows more easily for dispersibility.

The waste management environment will also contribute to the mobility or immobility of certain constituents. Effects of co-disposal with other wastes, the chemical characteristics, and rainfall may all play a part in the leaching of constituents from wastes.

Regardless of the waste's physical form or disposal environment there are a number of observed and theoretical chemical relationships that are considered underlying or basic to the discussion of leaching. These relationships are discussed in the following sections. Inorganic mobility and the chemical factors that tend to increase or decrease mobility are explored in the Section 1.1. The mobility of organics is discussed in Section 1.2. It should be noted that the discussion is theoretical; however, real-world examples are provided. While certain conditions may increase the mobility of certain constituents, those conditions in conjunction with other factors may yield different results. Therefore the following discussion is meant to act as a basis for initial consideration of how certain waste types may behave in a given waste management scenario.

1.1 Inorganic Mobility

Inorganic constituent mobility has been well studied for a select group of wastes; however, the speciation concepts have been well explored for a wide variety of inorganic constituents. These concepts and real-world examples are discussed below.

Determining which inorganic waste constituents will dissolve and be leached from waste depends on a multitude of factors. Factors affecting solubility of inorganic contaminants reviewed for this discussion include acid-base equilibria, oxidation-reduction reactions, coordinated metal-anion pair solubility, and pH. Metals described below include barium, beryllium, chromium, cobalt, nickel, arsenic, selenium, cadmium, antimony, mercury, and lead.

To summarize metal speciation and mobilization in waste environments, the following categories will be used in combination to describe the conditions under which chemical species become mobile: (1) oxidizing, (2) reducing, (3) acidic, (4) neutral, and (5) basic. Acid-base equilibria, solubility, oxidation-reduction, and pH were chosen because they are the most influential factors affecting mechanisms related to leaching. However, though these factors control many dissolution and mobilization mechanisms (i.e., precipitation reactions, complexation, adsorption, chemisorption, passivation, ion exchange, molecular transport), this study is based on simple solutions containing one cation-anion pair at specified redox and pH conditions. Reaction rates are not included in this discussion.

To compare solubilities of metals, experimentally measured or estimated solubility values were collected for the compounds of metals with the following anions:

- sulfides
- phosphates
- hydroxides
- chlorides
- oxides
- carbonates
- sulfates
- cyanides.

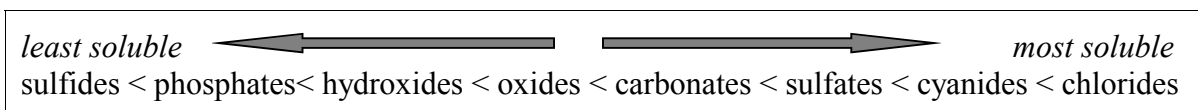
These compounds were chosen because they represent some common waste forms in which metals occur and they demonstrate a distinct gradient in solubility. By examining trends in the pH and redox effects that contribute to metal dissolution and mobility, the conditions that cause metal release and environmental transport in a waste management scenario may be described. Because most metals' behavior varies similarly under most conditions, a general discussion of solubility is followed by metal specific discussions.

1.1.1 Trends in Solubility of Metal Species

To discuss the solubility of a metal and to understand the processes regulating dissolved ion concentrations, all possible ionic and covalent species present in the system should be considered. However, for this study, solubility trends are discussed with regard to simple systems. Some examples of metal solubility and mobility from actual waste studies are also provided.

One of two values was used to observe the solubilities of metal compound, experimental or estimated values derived using solubility product constants (K_{sp}). Published experimental values were used whenever they were available. When deriving solubility using K_{sp} , it was assumed that the metal compound undergoes a dissociation when it dissolves, and the undissociated compound does not contribute to the concentration in the solution. This can introduce a negative bias, to varying degrees, in the solubility estimate. Table 1-1 provides some metal compound solubilities. Experimental and estimated solubilities are indicated.

Some general observations about soluble inorganic species in water are demonstrated by the following representation of increasing/decreasing solubility:



Soluble Compounds

- Metal-halide (Cl^- , Br^- , I^-) salts are generally soluble (except for Ag^+ , Hg^{2+} , Pb^{2+})
- Nitrates, perchlorates, and acetates are soluble (except for acetates of Ag^+ and Hg^{2+} which are moderately soluble)
- Sulfates are soluble (except for Sr^{2+} , Ba^{2+} , Pb^{2+} , not soluble) (Ca^{2+} and Ag^+ are moderately soluble)

Additionally, Benefield *et al.* (1982) show that extensive systematic treatment of equilibria using K_{sp} , pH and acid-base equilibria in conjunction with redox can be used to graphically represent metal compound speciation over a range of pH and Eh (volts). This becomes increasingly complex as the number of metal-anion pairs increases in the matrix.

Table 1-1. Solubilities of Metal-Anion Compounds in Water

Metal	Anion Species	Compound	g/L	Solubility Rating	Experimental/Estimated Value
Antimony	Sulfide	Sb_2S_3	1.75E-03	M	Experimental
	Chloride	SbCl_3	2390*	H	Experimental
Arsenic	Sulfide	As_2S_3	6.65E-04**	L	Experimental
	Sulfide	AsS_5	1.36E-03	M	Experimental
	Oxide	As_2O_3	1.77E+01**	H	Experimental
Barium	Phosphate	$\text{Ba}_3(\text{PO}_4)_2$	4.27E-04	L	Estimated
	Hydroxide	$\text{Ba}(\text{OH})_2$	3.98E+01	H	Estimated
	Sulfite	BaSO_3	1.07E-01**	M	Experimental
	Sulfate	BaSO_4	1.01E-02**	M	Experimental
Beryllium	Oxide	BeO	4.17E+02	H	Experimental
Cadmium	Hydroxide	$\text{Cd}(\text{OH})_2$	1.57E-03	L	Experimental
	Oxide	CdO	2.43E-03**	M	Experimental
	Carbonate	CdCO_3	2.72E-05	L	Estimated
	Cyanide	$\text{Cd}(\text{CN})_2$	2.47E-03	M	Experimental
Chromium	Sulfate	$\text{Cr}_2(\text{SO}_4)_3$	860*	H	Experimental
Cobalt	Sulfide	Co_2S_3	2.58E-23	L	Estimated
	Hydroxide	$\text{Co}(\text{OH})_3$	3.18E-03	M	Experimental
	Carbonate	CoCO_3	1.06E-04	L	Estimated
Copper	Sulfide	CuS	2.18E-13	L	Experimental
	Sulfide	Cu_2S	6.70E-15	L	Estimated
	Hydroxide	$\text{Cu}(\text{OH})_2$	2.10E-07**	L	Experimental
	Oxide	CuO	1.40E-08	L	Experimental
	Oxide	Cu_2O	8.60E-05	L	Experimental
	Cyanide	CuCN	1.60E-08	L	Estimated
	Chloride	CuCl	4.32E-02	M	Estimated
	Chloride	CuCl_2	637*	H	Experimental

Table 1-1. Solubilities of Metal-Anion Compounds in Water (continued)

Metal	Anion Species	Compound	g/L	Solubility Rating	Experimental/ Estimated Value
Lead	Sulfide	PbS	7.70E-04**	L	Experimental
	Phosphate	Pb ₃ (PO ₄) ₂	6.81E-07	L	Estimated
	Hydroxide	Pb(OH) ₂	9.90E-04	L	Estimated
	Oxide	PbO	1.41E+00**	H	Experimental
	Carbonate	PbCO ₃	1.70E-03	M	Experimental
	Sulfate	PbSO ₄	4.07E-02	M	Experimental
	Chloride	PbCl ₂	4.49E+00	H	Estimated
Mercury	Sulfide	HgS	1.25E-05	L	Experimental
	Hydroxide	Hg ₂ (OH) ₂	4.31E-07	L	Estimated
	Hydroxide	Hg(OH) ₂	5.90E-02	M	Experimental
	Oxide	HgO	2.58E-02**	M	Experimental
	Carbonate	Hg ₂ CO ₃	1.30E-03	M	Estimated
	Sulfate	HgSO ₄	3.90E-01	M	Experimental
	Sulfate	Hg ₂ SO ₄	2.75E+00	H	Estimated
	Cyanide	Hg(CN) ₂	9.30E+01	H	Experimental
	Chloride	Hg ₂ Cl ₂	4.25E-06*,**	L	Experimental
	Chloride	HgCl ₂	65.0	H	Experimental
Nickel	Sulfide	NiS beta	9.08E-12	L	Estimated
	Hydroxide	Ni(OH) ₂	1.27E-02	M	Experimental
	Carbonate	NiCO ₃	9.25E-02	M	Experimental
	Cyanide	Ni(CN) ₂	5.92E-02	M	Experimental

H = Highly soluble

M = Moderately soluble

L = Slightly soluble to insoluble

*g/L calculated from wt% assuming no loss in volume when the salt was dissolved in water

**Mean of two reported values

Source: compiled by SAIC from the sources listed in Section 5 of this report.

pH Control

pH largely controls metal containment in a solid matrix influenced by a solvent. Predicting any constituent's solubility as a function of pH must be done carefully. Though redox conditions largely influence solubility, the solubility of some metals is more dependent on pH than on redox potential (e.g., Pb).

Generally, metal cations are more soluble/mobile at low pH. Some metal anionic species are more soluble at high pH. Adsorption of metal cations and anions generally increases as pH increases thus reducing solubility. Metal hydroxides and oxides have low solubility in the range of pH 7.5-11, as depicted in Figures 1-1 and 1-2 (Conner, 1990). At higher pH (>12), in the absence of a strong reducing agent, metal hydroxides may become soluble. Greater effects on solubility of certain metals occur at extreme low and high pH (<2 and >12), respectively. Solubility over "transition" pH ranges (5-9) varies for most metal compounds and is more dependent on the overall influence of the waste environment. Amphoteric metals (e.g., chromium, lead) have higher solubility at both low and high pH.

Anions of weak bases become more soluble at low to mid-range pH (e.g., carbonates, sulfides, and phosphates). It is generally observed that hydrolysis occurring under strongly alkaline conditions leads to the precipitation of salts, and hydrolysis (hydrogen bonding/protonation) occurring under acidic conditions leads to the solubilization of salts. Hydrolyzed metals at low to mid-range pH act as weak acids, thus acidifying the solution and increasing the solubility of slightly soluble salts (Benefield, Judkins, and Weand, 1982).

pH greatly influences the reactions that occur at the surface of solids in contact with the solvating solution via the charge induced on solid and particle surfaces. Charged surfaces in turn influence hydration, adsorption, and complexation reactions. Thus the influence of the electro-chemical environment as a function of pH and redox potential should be observed together when predicting the stability boundaries, considering all possible metal cation and anion species.

Oxidation-Reduction Potential (redox potential) and Electron Activity

In simple and multi-component systems, the solubility gradient for many metals is largely dependent on the electro-chemical environment of solid and liquid phases (redox) in conjunction with pH. The solubility of polyvalent metals is more complex than for metals that have a strong tendency to exist in one oxidation state in solution, when bonded, and during chemical reactions (i.e., Cu, Zn, Cd, Pb, Ba, Co, Ni). Dissolution mechanisms are complex because a variety of redox influencing chemical species may exist at all ranges of pH. Furthermore, some metals are capable of anionic speciation and demonstrate different solubilities and amphoteric properties over varying pH (As, Se, Sb, Cr).

Figure 1-1. Solubilities of metal hydroxides as a function of pH (Adapted from Connor, 1990).

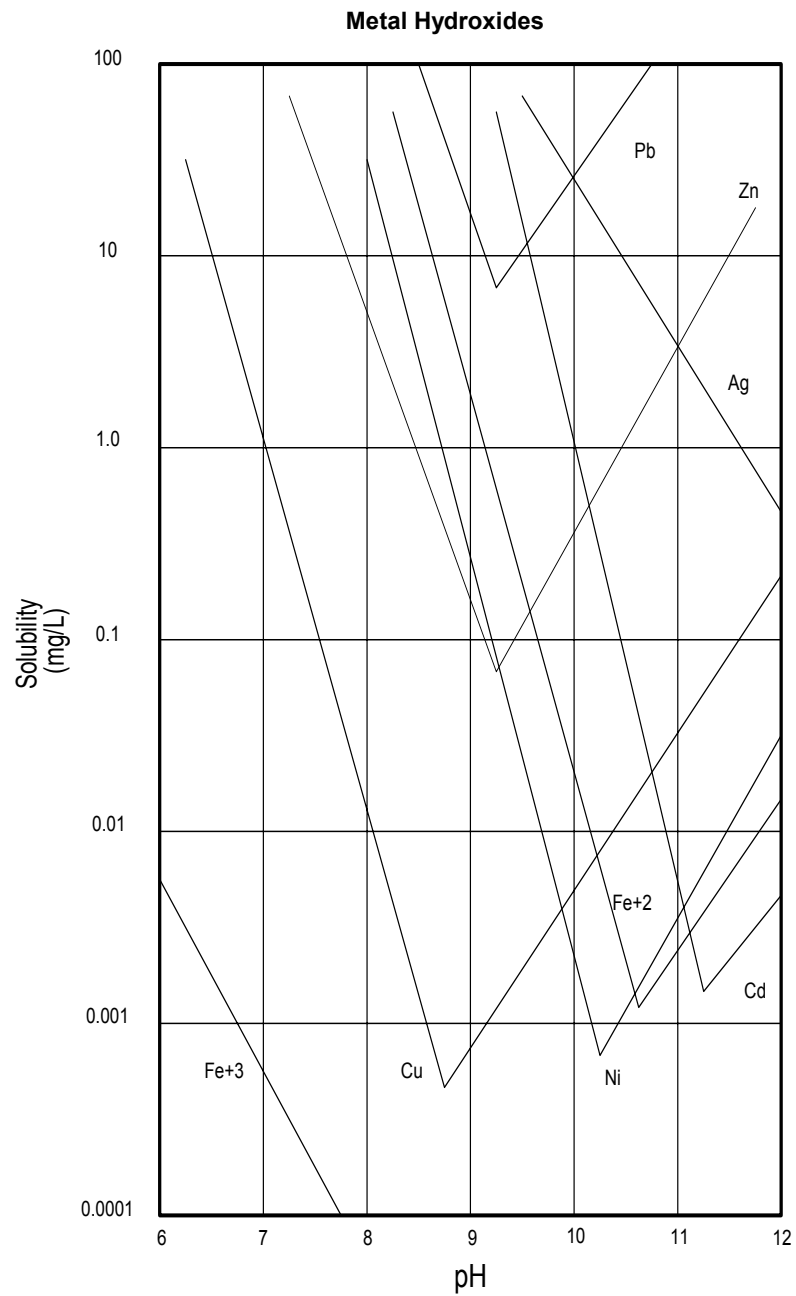
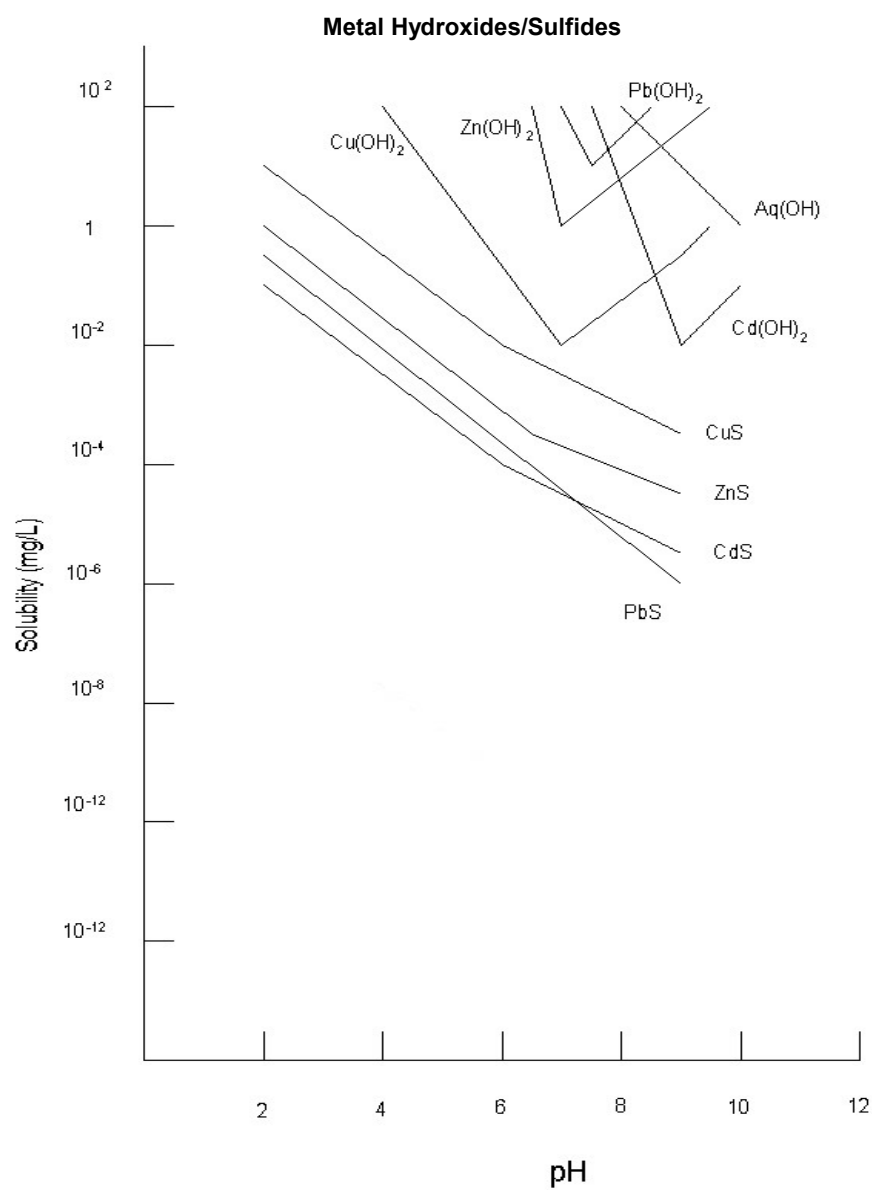


Figure 1-2. Solubilities of metal hydroxides and sulfides as a function of pH (Adapted from Connor, 1990).



In addition to the metals that have more than one valence state, other species in their elemental or ionic form (such as sulfur) have more than one valence state which also influences the redox process. Metals such as Cu and Cd, even though they have mainly one oxidation state, can be strongly influenced by redox processes.

In order to use the electrical potential to assess the likelihood of a reaction proceeding in the direction of metal dissolution, the species required for redox processes must be available in the system. In addition, since redox reactions involve the transfer of electrons, the use of electron activity (pe) is used as an approach (Drever, 1997). The activity of electrons does not correspond to a concentration, but the tendency of the system to provide electrons to any electron acceptor. Redox potential is a measure of the electrical charge required for a reaction involving a redox pair to proceed in the direction of oxidation or reduction. Thus a conventional means of discussing redox reactions can be done by using pe-pH and Eh-pH diagrams which conveniently display solubility transition boundaries based on speciation.

Oxidizing conditions are characterized by the redox potential of the system such that the dissolution of the metal species of concern is favored in the ionic environment, indicated by a positive electrical potential. Some natural oxidizing species include iron (III) oxide, manganese dioxide, and dissolved oxygen recharge water. Oxidizers found in wastes include peroxides, dichromates, and nitric acid. Some reducing species are iron(II) hydroxide and sulfides.

Knowledge of the redox potential of a system allows estimation of the possible speciation of the metal and its leachability at varying pH. This area, however, needs much more investigation in complex systems to understand what species are being affected by the overall redox potential of a system. In the following discussion, observations were made according to oxidation state classifications (e.g., +1, +2, +3, etc.).

The +2 metals (Cu, Zn, Cd, Pb, Ba, Co, and Ni) tended to show similar trends in solubility along pH and redox gradients. The +2 metals are generally more soluble in oxidizing conditions and less soluble under reducing conditions.

Two metals have unique oxidation states of +3 and +5, arsenic and antimony. Information was available for arsenic. Selenium is shown together with arsenic in the tables that follow, because both form anionic species over a range of conditions. However, Se and As solubilities are influenced differently by adsorption at varying pH.

In general, amphoteric metals in high pH environments are capable of being reduced and forming soluble metal anions from their higher oxidation state complexes (e.g., As, Sb). The contrary holds true as well. Amphoteric metals complexed at a low oxidation state are capable of being oxidized and solubilizing the metal ion at low pH. However, the mobility of these species is higher in acidic environments. Chromium and mercury behave uniquely compared to other metals due to their complex redox chemistry at varying pH.

Tables 1-2 and 1-3 show metal solubilities at general pH ranges under oxidizing and reducing conditions. These tables are only a general guide and may not predict the true solubility of a compound in a complex environment. Metal solubility and mobility information obtained from studies on simple systems is presented in Tables 1-2 and 1-3 in conjunction with information obtained from leaching studies of actual wastes (e.g., fly ash, bottom ash, municipal waste combustion ash) that supports these conclusions.

Table 1-2. Metal-Salt Speciation Under Oxidizing Conditions

	Acidic - Oxidizing	Neutral - Oxidizing	Basic - Oxidizing
Soluble	- CrO_4^{2-} and CrO_7^{2-} form stable and mobile anion		
	-all salts of Pb^{2+} , Cu^{2+} , Cd^{2+} , Ba^{2+} , Co^{2+} , Ni^{2+} - As^{5+} , SeO_4^{2-} -salts of Hg	- Pb^{2+} salts -salts of Hg	- Cu^{2+} , Cd^{2+} , Pb^{2+} at high pH (>12) -anionic species of As -salts of Hg
Moderately Soluble		-Gradient to higher pH: the salt solubilities of Pb^{2+} , Cu^{2+} , Cd^{2+} , Ba^{2+} , Co^{2+} , Ni^{2+} are limited by the formation of carbonates and hydroxides. - SeO_3^{2-}	

Source: compiled by SAIC from the sources listed in Section 5 of this report.

Table 1-3. Metal-Salt Speciation Under Reducing Conditions

	Acidic - Reducing	Neutral - Reducing	Basic - Reducing
Soluble	-When no sulfide is present, salts of Cd^{2+} , Ba^{2+} , Co^{2+} , Pb^{2+} - $\text{Cr}(\text{OH})_3^{3+}$		
	-salts of As and Sb remain soluble until strong reducing conditions are achieved.		
Moderately Soluble	-salts of Ni^{2+} when no sulfide is present	-with increase in pH the solubilities of Pb^{2+} , Cu^{2+} , Cd^{2+} , Ba^{2+} , Co^{2+} , Ni^{2+} salts are limited by the formation of carbonates and hydr/oxides.	

Source: compiled by SAIC from the sources listed in Section 5 of this report.

According to de Groot *et al.* (1989) pH is the main factor in controlling leachability [in fly ash], as illustrated in Table 1-4. The elements present in the form of anionic species (for example, As, Sb, Se, Mo and V) behave similarly. In contrast with literature information, limited solubility of anions at high pH (>11) has been observed. The metals Pb, Cu, Cd, and Zn show minimum solubility at high pH. To verify the pH dependence of all major elements normally found in fly ash extracts at pH 4 and liquid to solid (LS) ratio of 5, have been performed. By stepwise increase of the pH, by adding calcium oxide, the relation between pH and element concentrations in the solution has been established. Trace elements such as As, Sb, Se, Mo, and V show a characteristic maximum at neutral pH and a decrease in concentration towards lower and higher pH.

Table 1-4. Leaching characteristic as a function of acidity of the contact solution and the L/S ratio.

Concentration in Leachate	Trace elements form of anion L/S=5	pH	Observed solubility	Formation of insoluble compounds
Decrease	As, Sb, Se, Mo, V	>7	minimum	With calcium or precipitation / sorption as barium arsenate.
		<7	minimum	Solid phases , arsenic oxide, antimony oxide, molybdenum oxide, vanadium oxide
	Pb, Cu, Cd, Zn	>11	minimum	Hydroxide compounds
	Mg	>8	limited	Magnesium hydroxide
Maximum	As, Sb, Se, Mo, V	7		
	Al	6-7	minimum	Caused by gibbsite formation
		10	maximum	Related to pozzolanic activity
		>11	minimum	Ettringite formation (3 CaO.Al ₂ O ₃ .3CaSO ₄ .31 H ₂ O)
	Si	10	minimum	
		12	maximum	
Increase	Ca	high	limited	Calcium sulfate
	SO ₄	high	limited	Calcium sulfate

Source: compiled by SAIC from the sources listed in Section 5 of this report.

Comans and Meima (1987) show that the Ca chemistry of municipal solid waste bottom ash can exert a strong influence on the leaching of potential contaminants. Leaching of the heavy metals Cd, Cu and Pb is probably controlled by (hydr)oxide or carbonate minerals. The solubility minimum for these heavy metals lies between pH 8 and 9, and the solubility may increase as pH rises or decreases from the pH of minimum solubility.

1.1.2 Behavior of Specific Elements

Copper, Cadmium, and Lead (Drever, 1997)

The expected behavior of these metals in the environment can be summarized as follows: Under oxidizing conditions at low pH, they are all soluble and mobile. As the pH rises, their concentrations tend to decrease, first because of adsorption (particularly for Pb and Cu), and then because of the limited solubility of carbonates and oxides/hydroxides. Under reducing conditions, if sulfur is present, all should be immobilized as sulfides. If sulfur is absent, for Cd and Pb the solubility control will be the same as under oxidizing conditions; Cu should be insoluble at all pH values. Adsorption is generally less important in soil under reducing conditions because the most important substrates in soil for adsorption, Fe and Mn oxyhydroxides, tend themselves to dissolve.

Arsenic and Selenium (Drever, 1997)

Under oxidizing conditions, the dominant form of arsenic is the +5 oxidation state, which is present as arsenic acid and its anions (arsenate), corresponding closely to phosphoric acid and phosphate species. For selenium, the dominant form under oxidizing conditions is selenate, which is closely analogous to sulfate. As conditions become reducing, As (V) is reduced to As (III)-arsenious acid and arsenite anions. When sulfate reduction occurs, As precipitates as a sulfide; if sulfur is absent, it remains in solution as arsenious acid or an arsenite. Elemental arsenic should be a stable species under highly reducing conditions. For selenium, selenite species (analogous to sulfite) occur at intermediate redox levels, followed by elemental selenium and hydrogen selenide (analogous to hydrogen sulfide) species under strongly reducing conditions. Both arsenic and selenium may be incorporated into iron sulfides under reducing conditions. Figures 1-3 and 1-4 present pe-pH diagrams for arsenic and selenium, respectively.

Figure 1-3. Simplified pe-pH diagram for the system As-O-H₂O at 25° C and one atm.
 Total activity of sulfur species = 10⁻². Solubility is defined as a dissolved As species activity of 10⁻⁶. (Adapted from Drever, 1997)

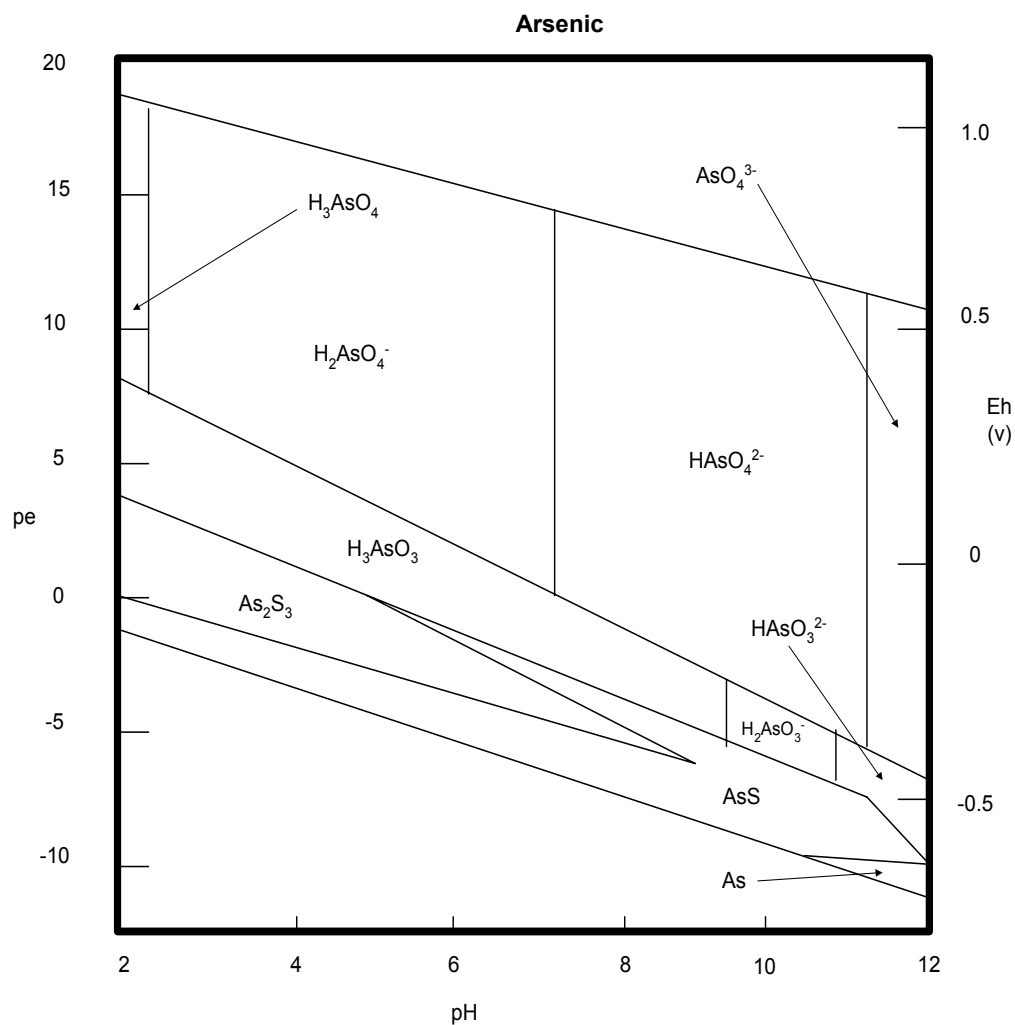
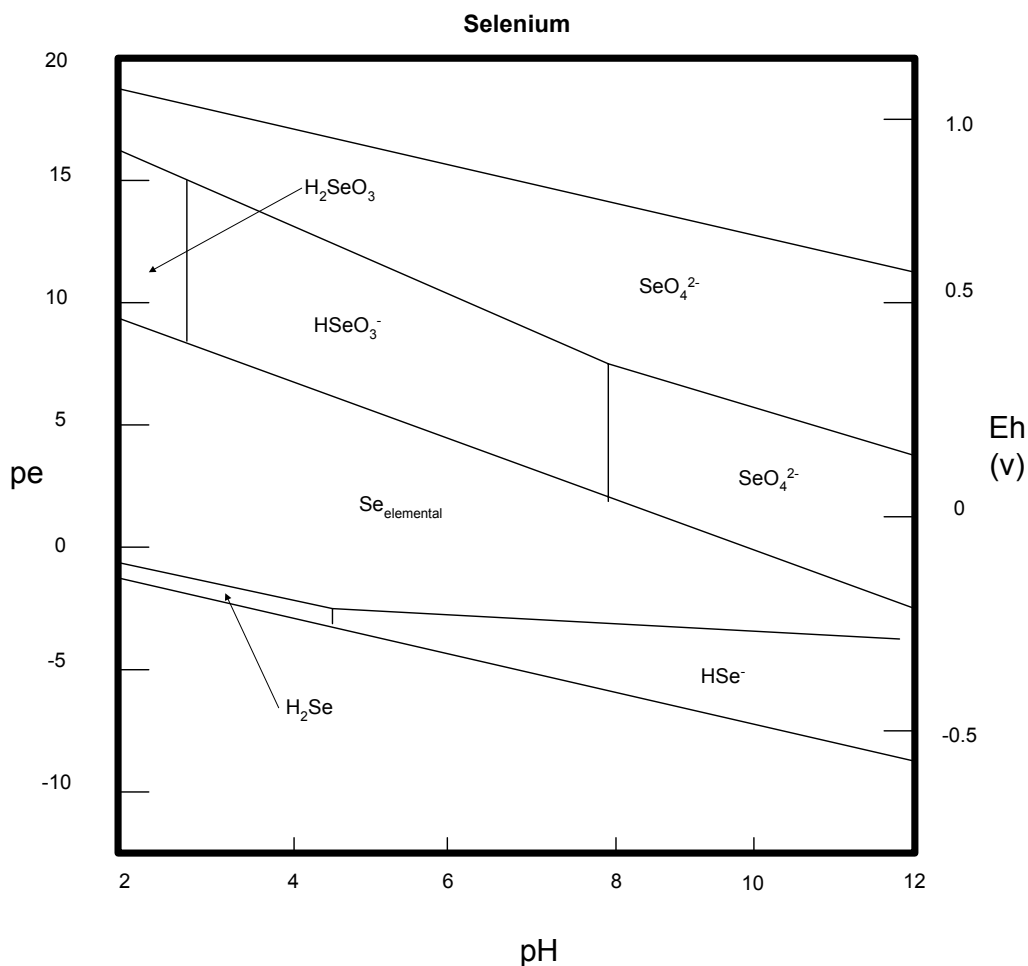


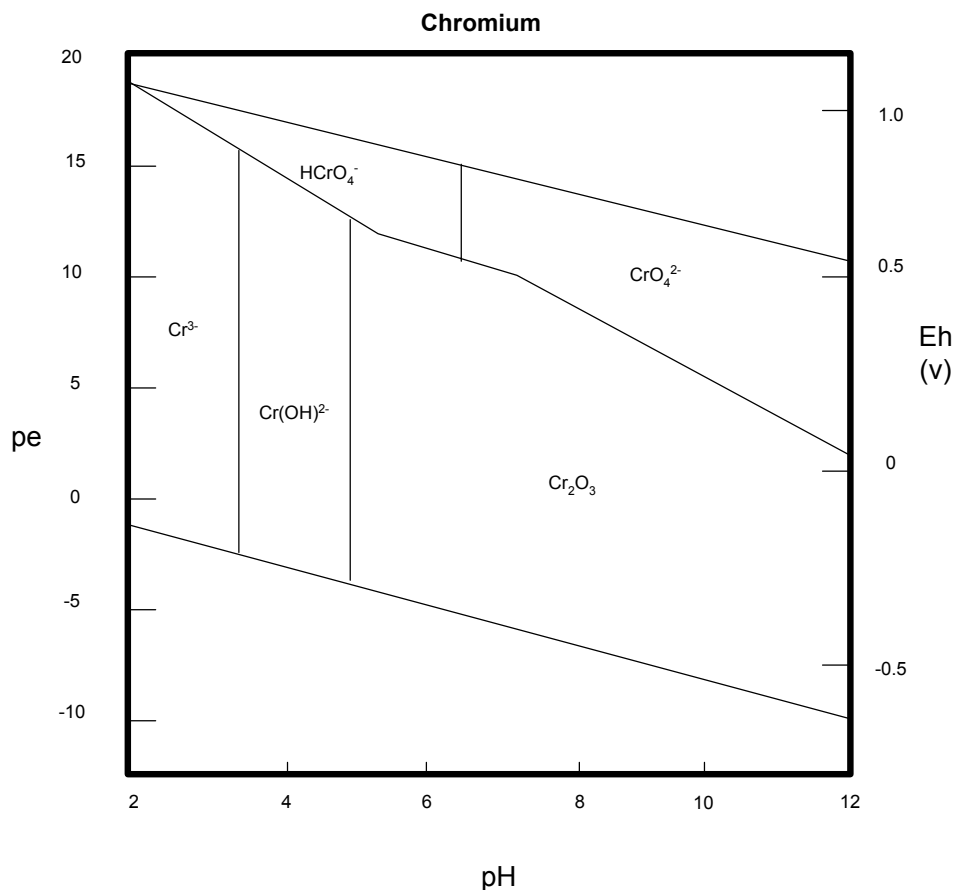
Figure 1-4. Simplified pe-pH diagram for the system Se-O-H₂O at 25°C and one atm. Solubility is defined as a dissolved Se activity of 10⁻⁶. (Adapted from Drever, 1997)



Chromium (Drever, 1997)

Under highly oxidizing conditions, the hexavalent form (chromate) is stable as an anion. It is not strongly adsorbed (adsorption edge at about pH 7) and is therefore mobile in the environment. Under intermediate and reducing conditions, Cr (III) is the stable oxidation state. It is insoluble in the neutral and alkaline pH ranges. It is soluble (largely as Cr(OH)²⁺) under acid conditions. In general, Cr (III) species are strongly adsorbed. Figure 1-5 presents a pe-pH diagram for chromium.

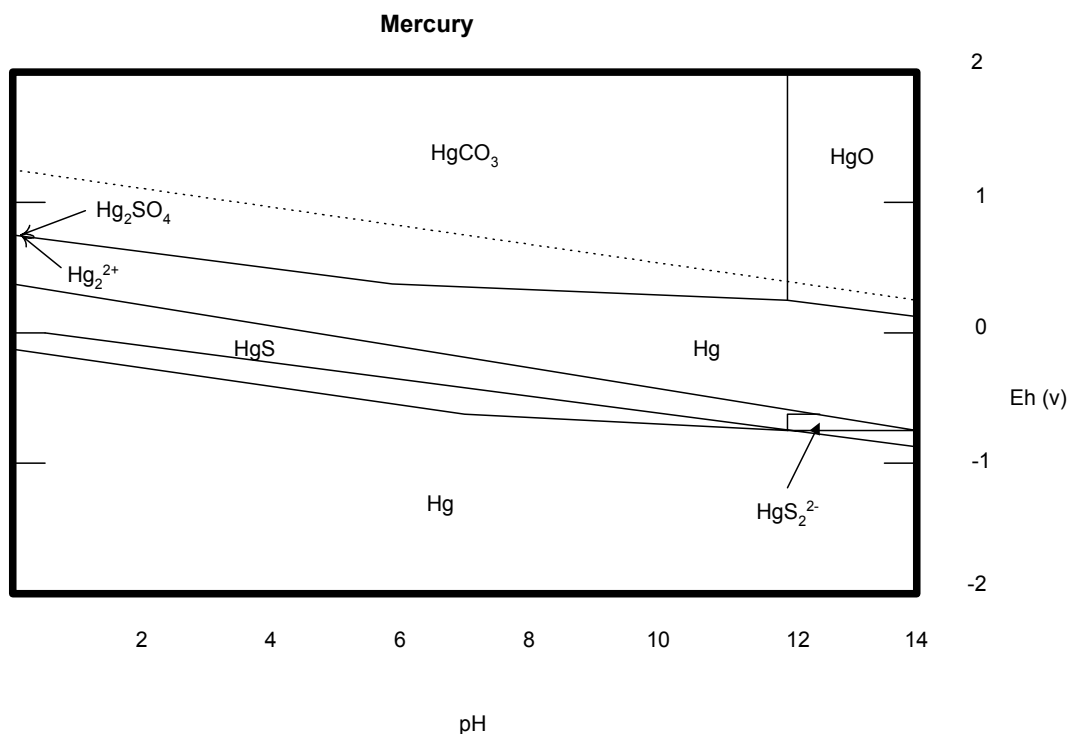
Figure 1-5. pe-pH diagram for the system Cr-O-H₂O at 25°C and one atm. Solubility is defined as a dissolved Cr activity of 10⁻⁶. (Adapted from Drever, 1997)



Mercury

The chemistry of mercury in the environment is highly complex. The common soluble form is the oxidized (mercuric) Hg²⁺ ion and its hydrolysis product Hg(OH)₂ (neutral species), with the reduced (mercurous) Hg₂²⁺ dication being less important. Elemental mercury has a large stability field. The elemental form is volatile and slightly soluble in water. Mercury sulfide is not mobile except in extreme alkaline conditions. Figure 1-6 presents a pe-pH diagram for mercury. (Drever, 1997).

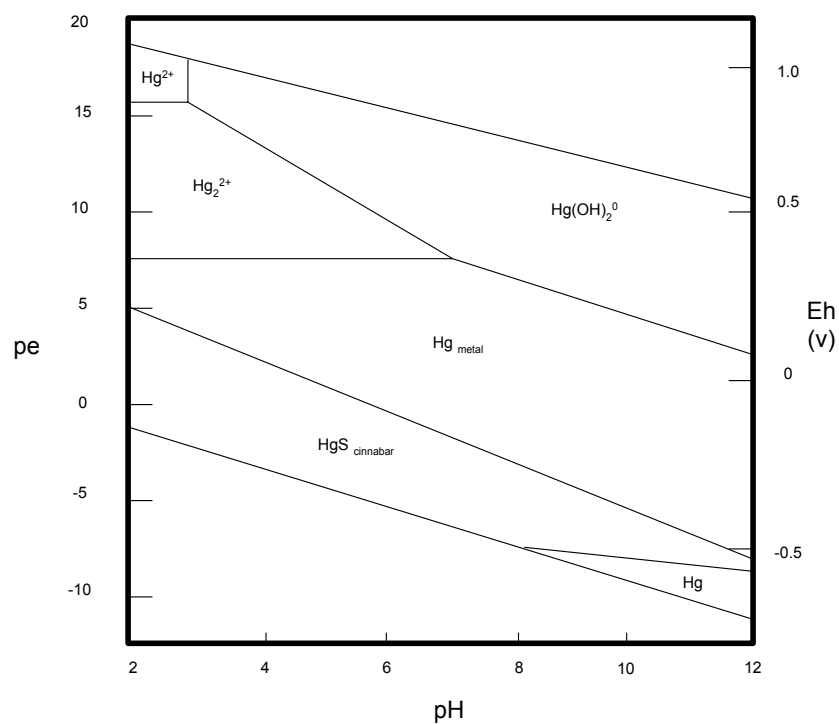
Figure 1-6. pe-pH diagram for the system Hg-S-O-H₂O at 25°C and one atm. Solubility is defined as a dissolved Hg activity of 10⁻⁶. Total activity of sulfur species = 10⁻². The diagram is the same in the absence of S species, with the HgS (cinnabar) field replaced by Hg (metal). In the presence of chloride, the Hg₂²⁺ may be replaced by the insoluble mercurous chloride (calomel). (Adapted from Drever, 1997)



In a metal-contaminated site, mercury exists in mercuric form (Hg²⁺), mercurous form (Hg₂²⁺), elemental form (Hg⁰), or alkylated form (e.g., methyl and ethyl mercury). Hg₂²⁺ and Hg²⁺ under oxidizing conditions are more stable than metallic mercury. Under mildly reducing conditions, both organically bound mercury and inorganic mercury compounds may be degraded to elemental mercury that can be converted readily to methyl or ethyl mercury by biotic and abiotic processes. Methyl and ethyl mercury are the most toxic forms of mercury. The alkylated mercury compounds are both volatile in air and soluble in water (Smith, 1995).

Mercury (II) forms relatively strong complexes with Cl⁻ and CO₃²⁻. Mercury (II) also forms complexes with other inorganic ligands such as F⁻, Br⁻, I⁻, SO₄²⁻, S²⁻, and PO₄³⁻. The insoluble HgS is formed under mildly reducing conditions (Smith, 1995). The stability of some mercury compounds under various Eh and pH conditions is shown in Figure 1-7.

Figure 1-7. Stability regions of mercury species in the sulfur carbonate water system. Hg = 0.001 M; S = 0.1 M; C = 0.1 M. (From USEPA, 1984. Mercury Health Effects Update: Health Issue Assessment, Final Report. EPA/600/8-84/019F.)



1.2 Organic Mobility

The mobility of organic constituents has received less study than the behavior of inorganics; however, there is a theoretical body of work that addresses the behavior of many organic compounds. For the purposes of this discussion, organic compounds included in the Hazardous Waste Identification Rule (HWIR) organics list were evaluated to explore for potential mobility using both theoretical and real-world examples. The relationship of chemical properties to leachate characteristics is best identified by properties such as octanol-water coefficients, pH, and solubility.

For many organic compounds, solubility often determines the leachate concentration. The solubility of some volatile constituents have been found to indicate that increasing solubility is related to increasing leachate concentration (Pavelka *et al.*, 1993). Alcohol constituents and halogenated hydrocarbons, ketones, and aromatics were found to follow this trend. Figure 1-8 shows the relationship for solubility and leachate concentration. Figure 1-9 indicates a strong correlation of leachate concentrations and solubility of the semi-volatile constituents.

Figure 1-8. Volatile concentration and solubility. (Adapted from Pavelka *et al.*, 1993)

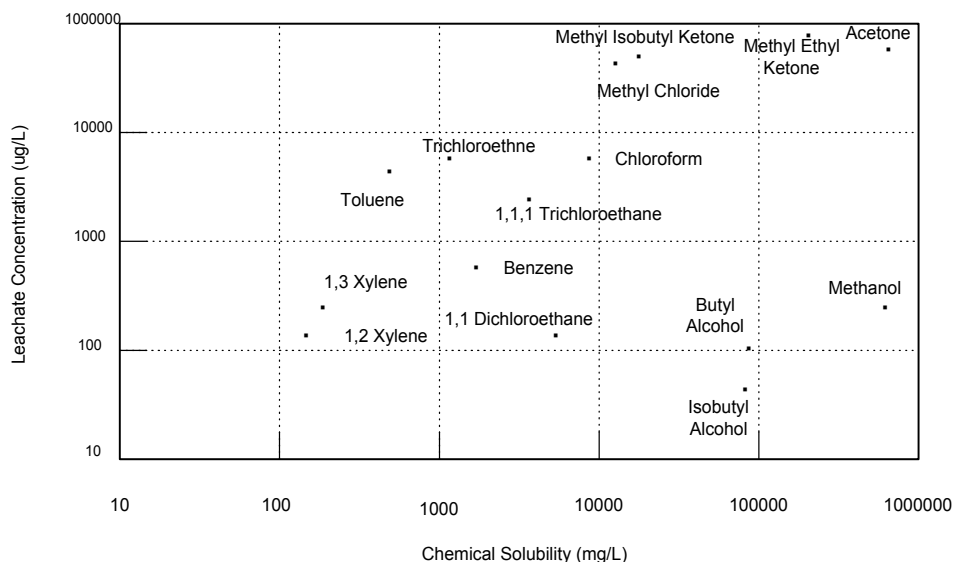
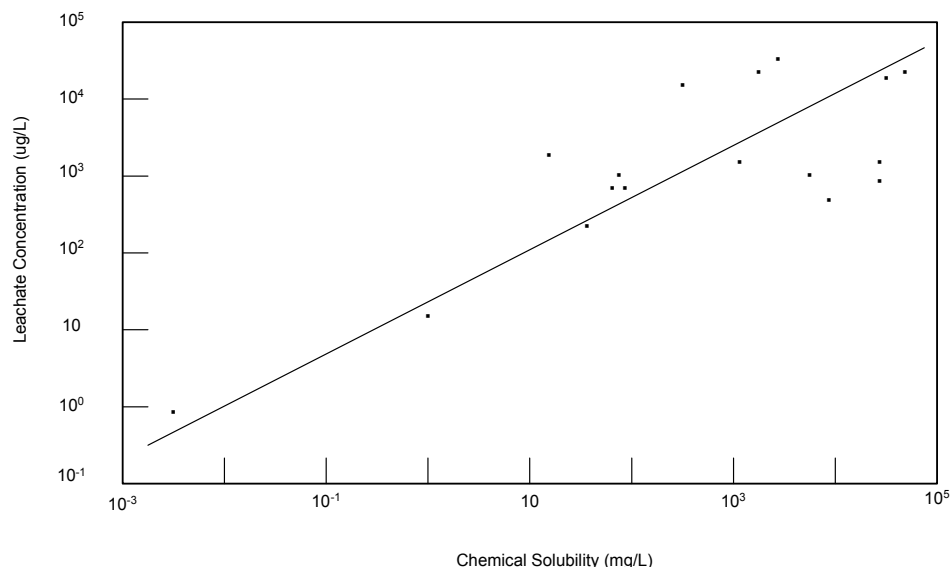


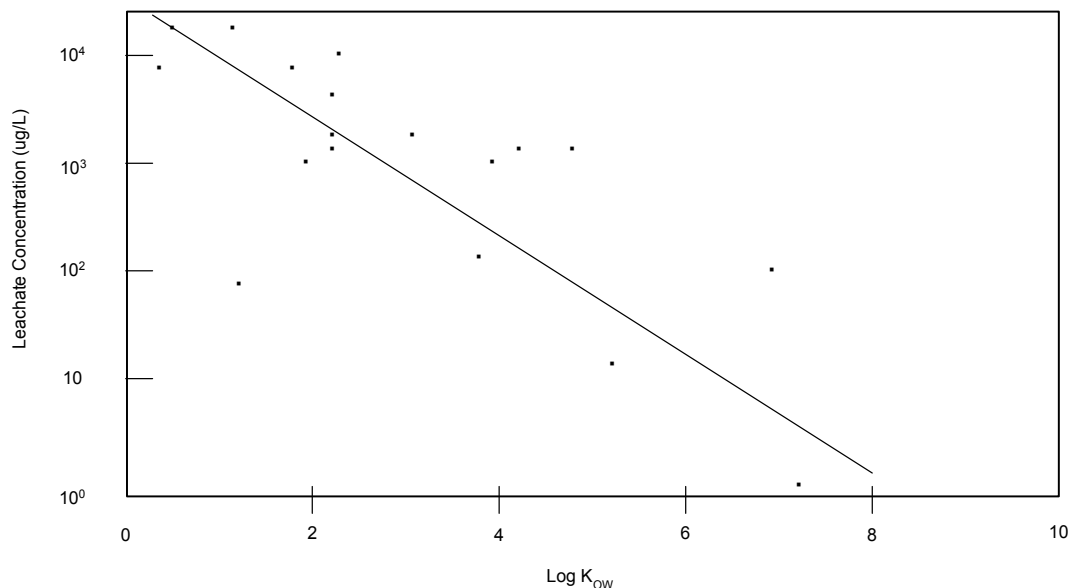
Figure 1-9. Semi-volatile concentration and solubility. (Adapted from Pavelka *et al.*, 1993)



1.2.1 Effects of pH on Leachability Of Organics

Many organic compounds can become more leachable if they are exposed to an acidic or alkaline leachant. The leachability of an organic in a neutral (pH = 7) aqueous leachant can be estimated by the organic's octanol/water partition coefficient (K_{ow}). However, new species can be formed from some organics in acid or alkali, usually cationic or anionic forms of the organic, with different K_{ow} and different leachability. The K_{ow} of a chemical should be related to the leachate concentration in an inverse way. Since the K_{ow} is a measure of a chemical hydrophobicity, the more hydrophobic a chemical is, the less soluble it should be. Pavelka *et al.* (1993) found that with volatile constituents leachate concentrations decreased as K_{ow} increased. Two distinct groups were identified by the study: alcohols; and halogenated hydrocarbons, aromatics and ketones. The semi-volatile constituents were also found to behave similarly to the volatiles (Figure 1-10). Constituents with low K_{ow} values were characterized as having high leachate concentrations (e.g., phthalic acid, phenol, and aniline).

Figure 1-10. Volatile concentration and Kow values. (Adapted from Pavelka *et al.*, 1993).



Acid Leachable Organics

In general, amines ($R-NH_2$, $R-NH-R$, $R-(R-)N-R$), amides ($R-C(=O)NH-R$), and other nitrogen-containing organics can form very water-soluble salts in the presence of strong acids like hydrochloric, nitric, phosphoric, or sulfuric. The amine or amide nitrogen becomes protonated, forming a cation that is much more water soluble than the neutral compound.

Table 1-5 lists compounds that react with strong acid-containing leaching media, changing their leachability and environmental mobility. Most of the compounds become protonated, forming a more mobile cation. Note, however, that two compounds in Table 1-5, endothall and the sodium salt of fluoroacetic acid are already very water leachable salts. (Endothall is the disodium salt of a dicarboxylic acid.) In the presence of acid, they are rendered neutral, and become less mobile in acidic media.

Table 1-5. Compounds Whose Leachability Changes In Acidic Media

CAS #	Chemical	Acid Mobility
145-73-3	Endothall	Less mobile
62-74-8	Fluoracetic acid, sodium salt	Less mobile
53-96-3	Acetylaminofluorene, 2-	More mobile
79-06-1	Acrylamide	More mobile
116-06-3	Aldicarb	More mobile
92-67-1	Aminobiphenyl, 4-	More mobile
504-24-5	Aminopyridine, 4-	More mobile
61-82-5	Amitrole	More mobile
62-53-3	Aniline	More mobile
2465-27-2	Auramine	More mobile
225-51-4	Benz[c]acridine	More mobile
92-87-5	Benzidine	More mobile
357-57-3	Brucine	More mobile
86-74-8	Carbazole	More mobile
106-47-8	Chloroaniline, p-	More mobile
5344-82-1	Chlorophenyl thiourea, 1-o-	More mobile
50-18-0	Cyclophosphamide	More mobile
2303-16-4	Diallate	More mobile
226-36-8	Dibenz(a,h)acridine	More mobile
224-42-0	Dibenz[a,j]acridine	More mobile
194-59-2	Dibenzo[c,g]carbazole, 7H-	More mobile
91-94-1	Dichlorobenzidine, 3,3'-	More mobile
60-51-5	Dimethoate	More mobile
60-11-7	Dimethylaminoazobenzene, p-	More mobile
119-93-7	Dimethylbenzidine, 3,3'-	More mobile
122-09-8	Dimethylphenethylamine, alpha, alpha-	More mobile
119-90-4	Dimethoxybenzidine, 3,3'-	More mobile
122-39-4	Diphenylamine	More mobile
122-66-7	Diphenylhydrazine, 1,2-	More mobile
51-79-6	Ethyl carbamate	More mobile
96-45-7	Ethylene thiourea	More mobile
151-56-4	Ethyleneimine (aziridine)	More mobile
52-85-7	Famphur	More mobile
640-19-7	Fluoracetamide, 2-	More mobile
302-01-2	Hydrazine	More mobile
123-33-1	Maleic hydrazide	More mobile
91-80-5	Methapyrilene	More mobile
16752-77-5	Methomyl	More mobile
101-14-4	Methylenebis, 4,4'- (2-chloroaniline)	More mobile
1615-80-1	N,N-Diethylhydrazine	More mobile
86-88-4	Naphthyl-2-thiourea, 1-	More mobile
134-32-7	Naphthylamine, 1-	More mobile

Table 1-5. Compounds Whose Leachability Changes In Acidic Media (continued)

CAS #	Chemical	Acid Mobility
91-59-8	Naphthylamine, 2-	More mobile
54-11-5	Nicotine	More mobile
88-74-4	Nitroaniline, 2-	More mobile
99-09-2	Nitroaniline, 3-	More mobile
100-01-6	Nitroaniline, 4-	More mobile
55-86-7	Nitrogen mustard	More mobile
126-85-2	Nitrogen mustard N-Oxide	More mobile
99-55-8	Nitro-o-toluidine, 5-	More mobile
56-57-5	Nitroquinoline-1-oxide, 4-	More mobile
55-18-5	Nitrosodiethylamine	More mobile
62-75-9	Nitrosodimethylamine	More mobile
924-16-3	Nitrosodi-n-butylamine	More mobile
10595-95-6	Nitrosomethylethylamine	More mobile
1116-54-7	N-Nitrosodiethanolamine	More mobile
621-64-7	N-Nitrosodi-n-propylamine	More mobile
86-30-6	N-Nitrosodiphenylamine	More mobile
4549-40-0	N-Nitrosomethyl vinyl amine	More mobile
59-89-2	N-Nitrosomorpholine	More mobile
615-53-2	N-Nitroso-N-methylurethane	More mobile
100-75-4	N-Nitrosopiperidine	More mobile
930-55-2	N-Nitrosopyrrolidine	More mobile
103-85-5	N-Phenylthiourea	More mobile
297-97-2	O,O-Diethyl O-pyrazinyl phosphorothioate	More mobile
152-16-9	Octamethylpyrophosphoramidate	More mobile
108-45-2	Phenylenediamine, —	More mobile
106-50-3	Phenylenediamine, p-	More mobile
25265-76-3	Phenylenediamines (N.O.S.)	More mobile
109-06-8	Picoline, 2-	More mobile
23950-58-5	Pronamide	More mobile
107-10-8	Propylamine, —	More mobile
110-86-1	Pyridine	More mobile
50-55-5	Reserpine	More mobile
57-24-9	Strychnine	More mobile
62-55-5	Thioacetamide	More mobile
79-19-6	Thiosemicarbazide	More mobile
62-56-6	Thiourea	More mobile
137-26-8	Thiram	More mobile
95-80-7	Toluenediamine, 2,4-	More mobile
823-40-5	Toluenediamine, 2,6-	More mobile
496-72-0	Toluenediamine, 3,4-	More mobile
95-53-4	Toluidine, o-	More mobile
106-49-0	Toluidine, p-	More mobile

Source: compiled by SAIC from the sources listed in Section 5 of this report.

Alkali Leachable Organics

Phenols (Ar-OH) and imides (R-C(=O)NHC(=O)-R) are the two organic functional groups represented on the HWIR list that can form an ionic species in the presence of an alkaline leachant. They are both weak acids, capable of giving up a proton in the presence of hydroxide, to form an organic anion, which is much more soluble than the neutral species.

Table 1-6 lists compounds that react with strong alkali-containing leaching media, changing their leachability and environmental mobility. Most of the compounds lose a proton, forming a more mobile anion. Note, however, that four compounds in Table 1-6, all acid salts, are already very water leachable. In the presence of alkali, they are rendered neutral, and become less mobile in alkaline media.

Polyfunctional Organics

Organics with multiple functional groups, including one that can be protonated in acid leachant, and one that can lose a proton in alkaline leachant, will be more leachable in both acids and alkalis. There are at least ten such compounds on the list. They are listed in Table 1-7. (A number of drugs and antineoplastic agents on the list have not been included, considering their low probability of occurrence in significant concentrations in industrial hazardous wastes.)

Table 1-6. Compounds Whose Leachability Changes in Alkaline Media

CAS #	Chemical	Alkali Mobility
[54-11-5]	Nicotine salts	Less mobile
51-75-2	Nitrogen mustard hydrochloride salt	Less mobile
302-70-5	Nitrogen mustard N-Oxide, HCl salt	Less mobile
636-21-5	Toluidine hydrochloride, o-	Less mobile
106-51-4	Benzoquinone, p-	More mobile
88-85-7	Butyl-4,6-dinitrophenol, 2-sec- (Dinoseb)	More mobile
59-50-7	Chloro-m-cresol, p-	More mobile
95-57-8	Chlorophenol, 2-	More mobile
108-39-4	Cresol, —	More mobile
95-48-7	Cresol, o-	More mobile
106-44-5	Cresol, p-	More mobile
131-89-5	Cyclohexyl-4,6-dinitrophenol, 2-	More mobile
120-83-2	Dichlorophenol, 2,4-	More mobile
87-65-0	Dichlorophenol, 2,6-	More mobile
94-75-7	Dichlorophenoxyacetic acid, 2,4- (2,4-D)	More mobile
56-53-1	Diethylstilbestrol	More mobile
105-67-9	Dimethylphenol, 2,4-	More mobile
534-52-1	Dinitro-o-cresol, 4,6-	More mobile
51-28-5	Dinitrophenol, 2,4-	More mobile
64-18-6	Formic Acid	More mobile
130-15-4	Naphthoquinone, 1,4-	More mobile
88-75-5	Nitrophenol, 2-	More mobile
100-02-7	Nitrophenol, 4-	More mobile
13256-22-9	N-Nitrososarcosine	More mobile
87-86-5	Pentachlorophenol	More mobile
108-95-2	Phenol	More mobile
108-46-3	Resorcinol	More mobile
58-90-2	Tetrachlorophenol, 2,3,4,6-	More mobile
108-98-5	Thiophenol	More mobile
95-95-4	Trichlorophenol, 2,4,5-	More mobile
88-06-2	Trichlorophenol, 2,4,6-	More mobile
93-76-5	Trichlorophenoxyacetic acid, 2,4,5- (245-T)	More mobile
93-72-1	Trichlorophenoxypropionic acid, 2,4,5- (Silvex)	More mobile
81-81-2	Warfarin	More mobile

Source: compiled by SAIC from the sources listed in Section 5 of this report.

Table 1-7. Compounds More Leachable in Acidic and Alkaline Media

CAS #	Chemical	Acid Mobility	Alkali Mobility
591-08-2	Acetyl-2-thiourea, 1-	More mobile	More mobile
2763-96-4	Aminomethyl-3-isoxazolol, 5-	More mobile	More mobile
115-02-6	Azaserine	More mobile	More mobile
541-53-7	Dithiobiuret	More mobile	More mobile
148-82-3	Melphalan	More mobile	More mobile
70-25-7	Methyl-nitro-nitrosoguanidine (MNNG)	More mobile	More mobile
50-07-7	Mitomycin C	More mobile	More mobile
759-73-9	N-Nitroso-N-ethylurea	More mobile	More mobile
684-93-5	N-Nitroso-N-methylurea	More mobile	More mobile
62-44-2	Phenacetin	More mobile	More mobile

Source: compiled by SAIC from the sources listed in Section 5 of this report.

2. LEACHATE GENERATION QUANTITIES IN LANDFILLS

Various processes affect the rate of leachate generation and its composition. The four factors listed below represent the ones most significantly affecting leachate quantity (Lu et al., 1985):

- Quantity of water at landfill surface. This includes effects such as climate (e.g., precipitation), topography (e.g., stormwater runoff), and irrigation (e.g., leachate recirculation).
- Landfill surface conditions. Not all of the water hitting the landfill surface will percolate through the landfill. Water can also evaporate (influenced by climate and cover material), or run off (influenced by cover material and topography). Indirectly, some of these effects are determined by whether the landfill is active or inactive with a cap.
- Refuse effects. Most of the landfills examined in the literature have been municipal solid waste landfills. However, there are differences both within MSW and between different waste types (e.g., industrial, hazardous, C&D). These include moisture retention effects and permeability.
- Underlying soil. Similarly to refuse effects, the moisture retention and permeability of underlying soil affects the rate at which leachate migrates to the ground water. This principally influences the quantity of leachate entering the subsurface rather than the quantity of leachate generated by the landfill.

Two relative metrics of leachate generation are reported most frequently in the literature: leachate generation per unit landfill area and liquid to solid (L/S) ratio. Leachate generation is commonly reported as a field observation while L/S is commonly reported as a laboratory or experimental leaching metric. These two metrics have significant differences and are not easily related to or correlated with one another. As discussed later leachate generation per unit area and time are a relatively consistent benchmark among landfills. Field observations of L/S ratios range more widely than leachate generation values and where reported are often calculated on differing bases. Most often, however, L/S ratios are reported as the abscissa (x-axis) in leaching experiments or methods development studies.

L/S ratios are of particular interest in such studies because of their significance for the design and interpretation of laboratory leaching tests. Specifically, leaching tests require the addition of liquid to a solid (usually waste) matrix. Comparing the quantity of liquid added per unit of solid material in the test procedure to L/S ratios observed in actual landfills is critical to interpreting test results.

From a practical standpoint, L/S ratio can be calculated by dividing the total leachate generated over a period of time by the total quantity of waste in the landfill. The total quantity of leachate

generated is dependent on time, since liquid could percolate through the landfill indefinitely and also at different rates due to the factors described above. For an active landfill, both the leachate generation rate and the waste quantity are dynamic (i.e., leachate generation changes as the landfill is expanded, while waste volume increases daily). For a closed landfill, the waste volume is constant but, as time goes on, the cumulative quantity of leachate generated from the landfill increases. For purposes of this analysis we have defined L/S as the ratio of annual mass of leachate generated by a landfill or landfill cell to the cumulative mass of waste disposed in that landfill or landfill cell. The analysis that follows serves (1) to identify values of leachate generation rates and L/S ratios found in the literature and other case studies, and (2) to quantitatively evaluate, using a database of approximately 250 landfills developed by EPA's Office of Water, the way a number of factors influence leachate generation rate.

2.1 Information Sources

Four types of information sources are presented here: (1) recent data from EPA's Office of Water's effluent guidelines development work, (2) data previously developed from EPA's Subtitle D survey from the 1980s, (3) data from the literature, and (4) data taken from various case studies. Each of these sources presents data representing different landfill designs, waste types, climate, etc., allowing for an examination of the various factors influencing generation rate. The four data sources are discussed below.

Effluent guidelines for the landfills point source category were proposed on February 6, 1998 (63 Federal Register 6425). In developing these standards, EPA's Office of Water collected data specific to landfills using a questionnaire (among other data sources), with 1992 as the base year. Approximately 250 landfills are represented in the survey results, representing hazardous, municipal, and Subtitle D landfills. These data are presented in Appendix E.

For comparison to the data obtained from EPA's Office of Water, another large scale database available is the distribution of Subtitle D landfills collected by EPA in the late 1980's. These data are still used by EPA, for example in the Monte Carlo framework of the hazardous waste identification rule (64 Federal Register 63382, November 19, 1999). These data predominantly represent private or captive industrial landfills (i.e., landfills managing waste from a single industrial plant or several industrial plants owned by the same company). Complete landfill dimension data are available for approximately 500 landfills. As an estimate to determining leachate generation rate, each landfill is identified with 1 of 97 climatic areas of the U.S., which correspond to a fixed infiltration rate through a "look-up" table. The infiltration rates are calculated using various assumptions and the HELP model.

Data from individual sites from the literature are extracted. Although in most cases the researchers did not make the investigation of L/S ratio or leachate generation rate a principal effort, sufficient information exists from these sources to calculate this quantity. Specifically, five papers were identified that allowed the calculation of L/S ratios for thirteen different sites, while three papers were used in calculating normalized leachate generation rates (rate per area) at eight sites. These sites were exclusively municipal landfills. Appendix C presents the citations and more detailed data concerning these sites.

Finally, SAIC has initiated the collection of data from "case studies." These data are from various sources including past EPA programs and more current information from states where leachate characteristics from a single landfill are identified. Appendix D presents the data in a "site-by-site" format.

2.2 Values of Liquid-to-Solid Ratio and Leachate Generation Rate Found

2.2.1 Summary of Data

Tables 2-1 and 2-2 present an overview of the data from the sources discussed above. Table 2-1 summarizes liquid to solid (L/S) ratios, which are calculated as annual leachate generation (in volume per year) divided by total waste accumulated (in volume), resulting in units of 1/years (or years⁻¹). The calculated liquid to solid ratios are fairly consistent between the four various data sources (i.e., within the same order of magnitude), and they are all much less than the L/S ratio of 20:1 used in the TCLP. The TCLP laboratory procedure uses a L/S ratio of 20:1. As shown in Table 2-1, the quantity of leachate generated in a fixed period of time (one year), as compared to the quantity of waste in the landfill, is much less than 20:1 (with differences of two or more orders of magnitude). Therefore, if anything, the 20:1 ratio is representative of the quantity of leachate generated after hundreds of years.

In Table 2-2 provides leachate generation rates are provided for the various sources. These data are calculated as leachate generation (in gallons per day) divided by landfill area (in acres), resulting in units of gallons/acre-day. The median generation rates between sources are similar. These summaries demonstrate that the values obtained from one source are of the same magnitude as data obtained from other sources.

Table 2-1. Summary of Liquid-to-Solid Ratios for all Sources

Source of Data	Number of Data Points	Liquid to Solid Ratio (years ⁻¹)		Additional Data Analysis Performed
		Median	Range (10th to 90th Percentiles)	
Office of Water	234	0.012	0.0004 to 0.23	Landfill type, operational status, and precipitation
HWIR/HELP	487	0.06	0.02 to 0.13	None (data set lacks flexibility)
Case Studies	6	0.05	0.0003 to 0.15	Operational status
Literature	13	0.04	0.003 to 1.9	Operational status
TCLP	--	20	--	For comparison

Table 2-2. Summary of Leachate Generation Rates for all Sources

Source of Data	Number of Data Points	Leachate Generation Rate (gallons/acre-day)		Additional Data Analysis Performed
		Median	Range (10th to 90th Percentiles)	
Office of Water	252	290	1 to 2,100	Landfill type, operational status, and precipitation
HWIR/HELP	487	410	70 to 1,100	None
Case Studies	8	320	40 to 2,100	Operational status
Literature	8	130	30 to 620	Operational status

2.2.2 EPA Office of Water Data

Operational Status

When a landfill is closed, cover materials are placed over it to reduce infiltration. These materials include natural soil, clay, synthetics, and/or vegetation. Several studies in the literature have shown that infiltration rate is in fact reduced after a landfill is closed in this way (these cases are in Appendices C and D). Table 2-3 shows data extracted from the Office of Water database for active and inactive cells, showing a similar reduction. This table presents leachate generation rate in units of gal/ac-day.

Table 2-4 presents L/S ratios using two different computational methods. All data are from the Office of Water survey. In the first set of data, the L/S ratio is calculated by dividing the landfill's leachate generation rate (given in units of gal/ac-d) by average cell depth. In the second set of data, the L/S ratio is calculated by dividing the leachate flow rate (in gal/d) by the total waste volume (in units of cubic yards). The purpose of this comparison is to show if certain data elements in the survey yield vastly different results, which would imply some level of inconsistency in the data. As shown in Table 2-4, however, the data are consistent.

Table 2-3. Leachate Generation Rates by Operational Status from Office of Water Data

Type of Landfill	Number of Data Points	Leachate Generation Rate (gallons/acre-day)		Statistical Significance ^A
		Median	Range (10 th to 90 th Percentile)	
Active	191	500	30 to 3500	Active and inactive rates are statistically different at 95 th % significance level
Inactive	127	67	0 to 1000	

A. Statistical significance was determined using the t-test for differences between two population means.

Table 2-4. Liquid-to-Solid Ratios by Operational Status from Office of Water Data

Type of Data		Number of Data Points	Liquid-to-Solid Ratio (years ⁻¹)		Statistical Significance ^A
			Median	Range (10 th to 90 th Percentile)	
Normalized leachate flow/ landfill depth	active	178	0.014	0.00044 to 0.17	Active and inactive rates are statistically different
	inactive	97	0.005	0.00040 to 0.049	
Leachate flow/ landfill volume	active ^B	185	0.016	0.00034 to 0.22	Statistical significance not determined
	inactive ^B	49	0.0067	0.00051 to 0.41	

A. Statistical significance was determined using the t-test for differences between two population means at the 95% level.

B. “Inactive” indicates a landfill with only inactive cells. “Active” indicates a landfill with at least one active cell; it may or may not also have inactive cells.

Landfill Type

The three categories of landfills used in this analysis of the Office of Water survey are municipal, Subtitle D, and hazardous. These same distinctions were used in developing the proposed effluent guidelines. It should be noted that, in order to provide a sufficient sample size for analysis, the latter two categories are broader than those discussed in Section 3 of this report. Specifically, Subtitle D landfills include non-hazardous industrial waste landfills (both codisposal and monofill) and construction and demolition (C&D) landfills. Hazardous waste landfills include both commercial Subtitle C landfills and captive hazardous waste landfills from various industries.

Leachate generation rates and L/S ratios may vary due to differences in landfill type. Tables 2-5 and 2-6 present data for these parameters based on distinctions between hazardous, industrial, and municipal landfills, and their operational status. Figures 2-1 and 2-2 display the data in graphical form. The data show that differences are apparent between active and inactive landfills for each landfill type. Differences between landfill types, however, are not as apparent.

Table 2-5. Leachate Generation Rates by Landfill Type from Office of Water Data

Type of Landfill		Number of Data Points	Leachate Generation Rate (gallons/acre-day)		Statistical Significance ^A
			Median	Range (10 th to 90 th Percentile)	
Hazardous	active	33	493	11 to 2600	Active and Inactive rates are not statistically different
	inactive	43	88	0 to 1400	
Municipal	active	122	500	33 to 2300	Different at a 95 th % significance level
	inactive	69	58	0 to 840	
Subtitle D	active	36	509	8 to 5400	Different at a 95 th % significance level
	inactive	15	100	0 to 500	
All (from Table 2-3)	active	191	500	30 to 3400	Different at a 95 th % level
	inactive	127	67	0 to 1000	

A. Statistical significance was determined using the t-test for differences between active and inactive population means.

Table 2-6. Liquid-to-Solid Ratios by Landfill Type from Office of Water Data.

Type of Landfill	Number of Data Points	Liquid-to-Solid Ratio (years ⁻¹)		Statistical Significance ^A
		Median	Range (10 th to 90 th Percentile)	
Hazardous	61	0.008	0.00038 to 0.41	L/S ratio for Subtitle D landfill is statistically higher than population as a whole
Municipal	132	0.010	0.00036 to 0.098	
Subtitle D	41	0.060	0.0012 to 0.62	
All (from Table 2-1)	234	0.012	0.00038 to 0.23	

A. Statistical significance was determined using the t-test for differences between two population means at the 95% level.

Figure 2-1. Leachate Generation Rates by Landfill Type and Operational Status.

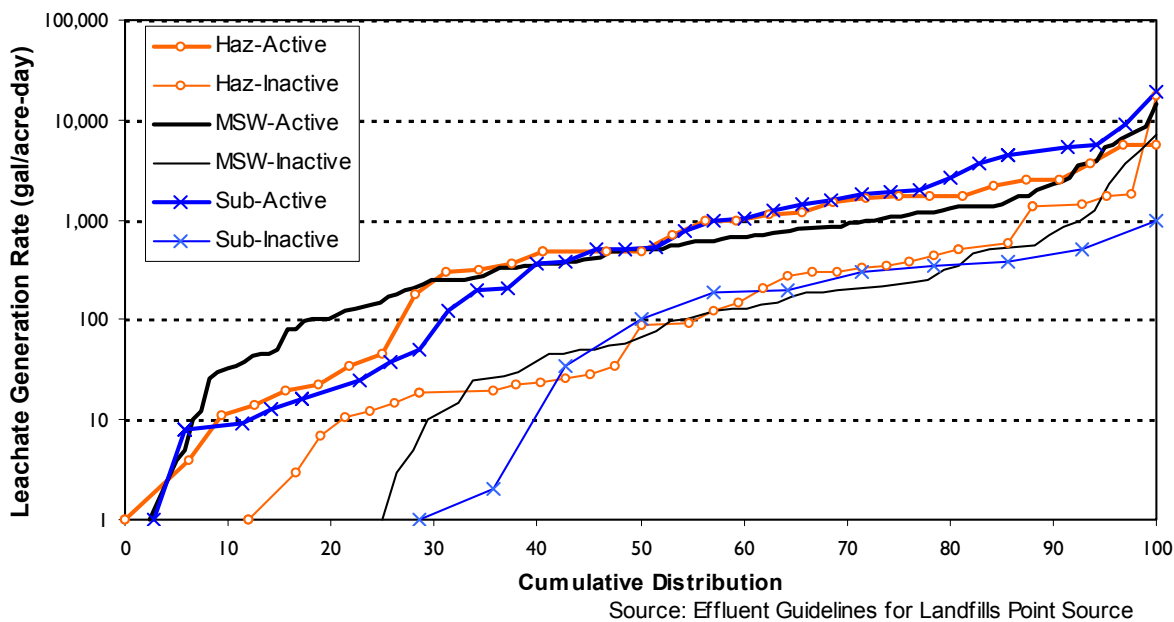
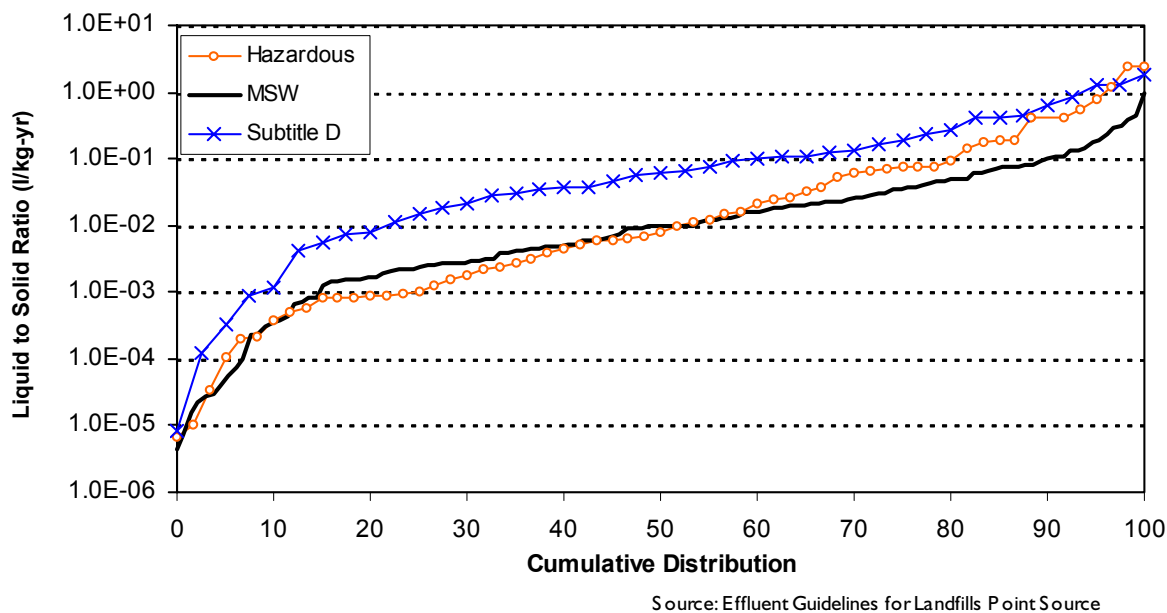


Figure 2-2. Liquid to Solid Ratio by Landfill Type: Both Active and Inactive.



Precipitation

Leachate generation rates and L/S ratios also vary due to differences in landfill location. Tables 2-7 and 2-8 present data for these parameters based on distinctions between precipitation. Distinctions are also made between active and inactive cells. Figures 2-3 and 2-4 display the data in graphical form.

Figure 2-3 shows that leachate generation rate increases with increasing precipitation in inactive landfills. Figure 2-4 shows that L/S ratio also increases with increasing precipitation.

Table 2-7. Leachate Generation Rates by Precipitation Rate from Office of Water Data.

Amount of Precipitation		Number of Data Points	Leachate Generation Rate (gallons/acre-day)		Statistical Significance ^A
			Median	Range (10 th to 90 th Percentile)	
<40 inches	active	83	340	4 to 1800	Different at a 95 th % significance level
	inactive	50	40	0 to 720	
40 to 60 inches	active	84	610	46 to 2600	Different at a 90 th % significance level
	inactive	53	92	0 to 700	
>= 60 inches	active	24	970	33 to 5600	Different at a 95 th % significance level
	inactive	24	200	0 to 1350	
All	active	191	500	30 to 3500	Different at a 95 th % significance level
	inactive	128	67	0 to 1000	

A. Statistical significance was determined using the t-test for differences between two population means.

Table 2-8. Liquid-to-Solid Ratio by Precipitation Rate from Office of Water Data.

Amount of Precipitation	Number of Data Points	Liquid-to-Solid Ratio (years ⁻¹)			Statistical Significance ^A
		Median	Mean	Standard Deviation	
<40 inches	192	0.0095	0.062	0.19	Precipitation is significant for active landfills (at a 90% level).
40 to 60 inches	208	0.015	0.10	0.31	
>= 60 inches	68	0.022	0.26	0.50	
All (from Table 2-1)	234	0.012	0.11	0.31	Precipitation is not significant for inactive landfills.

A. Regression analysis was performed to examine the relationship between precipitation and leachate generation. Because of the significant differences found between active and inactive landfills, the analysis was performed separately for each group. In both cases, precipitation was found not to be a very strong predictor of leachate generation (i.e., the coefficient of determination, R^2 , was on the order of 0.01). For active landfills, however, the relationship between precipitation and leachate generation still was found to be statistically significant at the 90 percent level (i.e., based on analysis of variance of the regression and significance tests on the regression estimators). The relationship was not significant for inactive landfills. These results suggest that, for active landfills, precipitation does influence leachate generation, although other factors appear to have a more substantial effect. Further analysis would be required to isolate the effects of these other factors.

Figure 2-3. Leachate Generation Rates by Precipitation Rate and Operational Status.

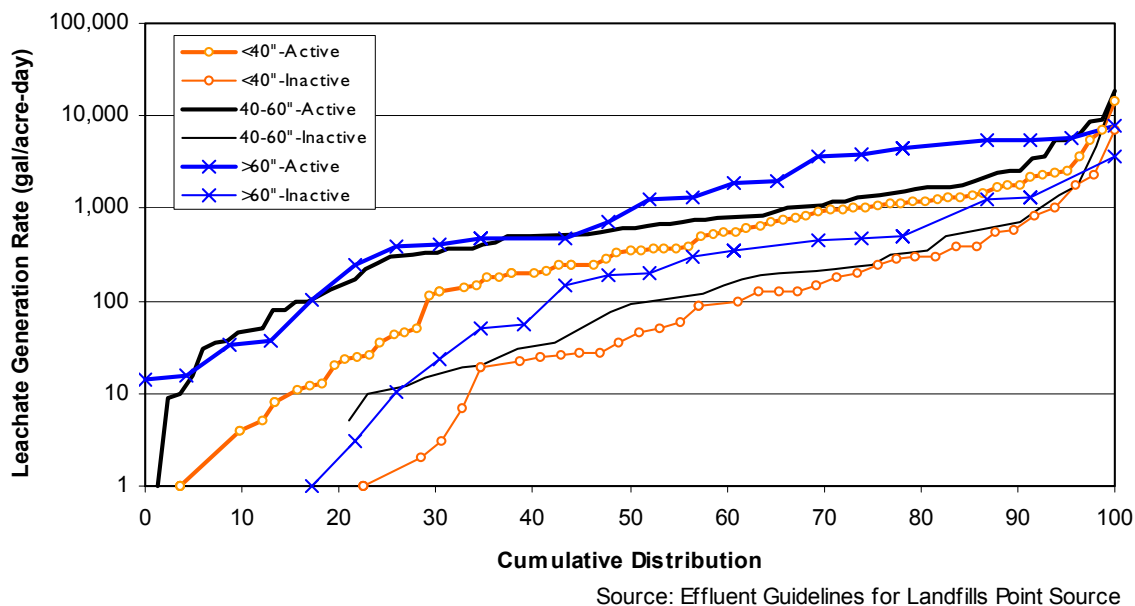
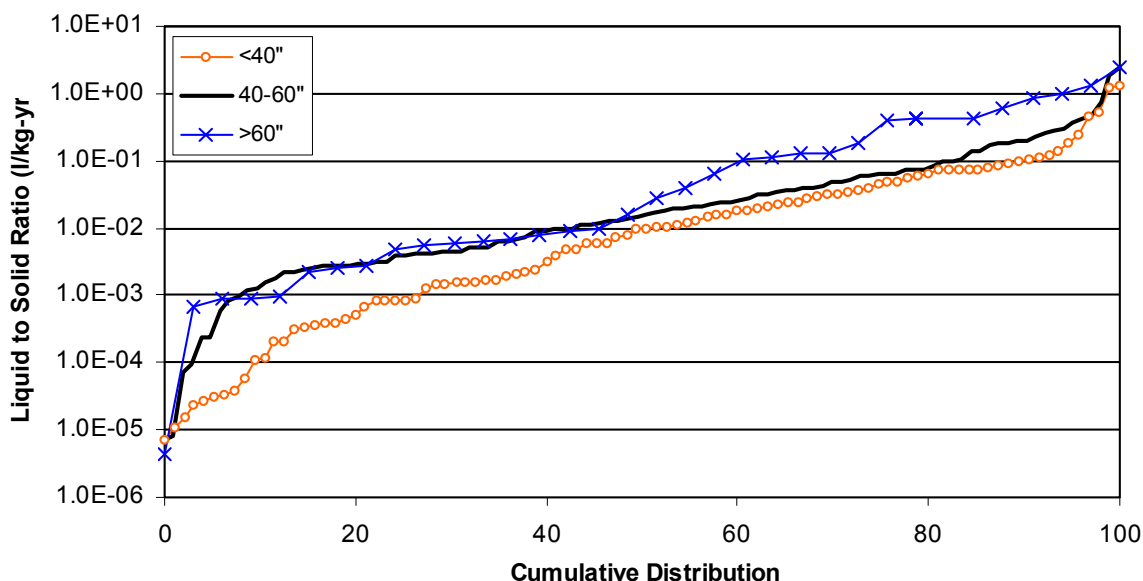


Figure 2-4. Liquid to Solid Ratio by Precipitation Rate: Both Active and Inactive.



Source: Effluent Guidelines for Landfills Point Source

2.2.3 Use of Other Data

Other data sources were investigated to verify or supplement the data from the EPA Office of Water data set. As shown in Tables 2-1 and 2-2, these other data sets presented results of similar magnitude, and therefore confirm the reasonableness of the EPA Office of Water data.

These data sources could also be used in identifying the effect of parameters such as landfill operation on L/S ratio and leachate generation rate. The Office of Water data showed that the values of both variables are lower for inactive landfills than for active landfills. Similar anecdotal conclusions are available from the literature and case study information in the Appendices C and D.

3. LEACHATE COMPOSITION AND PROPERTIES

This section presents summary statistics on leachate composition from the characterization database developed in conjunction with this report. It also discusses some of the more fundamental of these characteristics based on the available literature on contaminant leaching processes. Where the data are sufficient to do so, it compares leachate characteristics across landfill types.

This section begins with a description of the characterization database and the sources combined to create the database (Section 3.1). It then presents summary statistics and discusses leaching processes for several types of landfills. Municipal solid waste (MSW) landfills and leachate characteristics are discussed first (in Section 3.2) because of the extensive body of literature available. Sections 3.3 through 3.5 discuss the leachate characteristics of three other types of landfill that are well-represented in the database. These landfill types are as follows:

- Construction and demolition debris (C&D) landfills,
- Industrial codisposal landfills (these are a set of older landfills that have managed multiple types of waste from multiple generating sites throughout their history, including non-hazardous industrial waste, hazardous waste, and municipal solid waste), and
- Commercial hazardous waste landfills (Subtitle C landfills).

Section 3.6 presents comparative statistics for these four types of landfills, with discussion of the apparent fundamental differences. Section 3.7 presents summary statistics for other types of landfills represented in the database. The landfills discussed in Section 3.7 all are captive landfills managing waste from a single industrial plant or several industrial plants owned by the same company. Statistics in Section 3.7 are presented according to the waste generating industry.

3.1 Characterization Database

An integral part of this study was the development of a comprehensive database of landfill leachate characteristics. The search for data to incorporate into the database encompassed industry and Federal and State government sources. Data were accepted into the database if they met the following criteria:

- They represented leachate characteristics on an individual sample basis.
- They included at least some information regarding the type of landfill from which the data were taken.
- They were from a reliable source.
- They were available in an electronic form that could be incorporated into the database without extensive modification or manual data entry.

The search for data did not attempt to employ any statistical sampling approach. That is, the data are not necessarily a representative sample by geographic region, landfill type, or any other criterion. The database simply includes all of the readily available data that met the acceptance criteria above.

Each of the data sets resulting from the search was combined into a single electronic database that accompanies this report. The resulting database (entitled LEACH 2000) includes data for conventional pollutants, metals, and organics in leachate from a variety of landfill types. The LEACH 2000 data is the basis for the summary statistics presented in the sections below. In order to represent typical landfills of each type, rather than extreme conditions, the summary statistics presented in this report exclude statistical outliers found in the data. These statistical outliers (with the exception of certain outliers in the Wisconsin data set, discussed below), however, have been retained in the electronic database to allow for possible future investigation of their sources. The following paragraphs describe the specific data that was collected and incorporated in the LEACH 2000 database.

Two data sets were obtained from industry sources: data representing 60 MSW landfills from Browning Ferris Incorporated (BFI) and data from a 1992 Chemical Waste Management (CWM) study of leachate quality. The CWM study includes data from 47 landfills, including commercial hazardous waste landfills, industrial codisposal landfills, and MSW landfills.

Two data sets also were obtained from previous EPA research efforts. The first was a set of data for 21 C&D landfills compiled by ICF Incorporated for the Office of Solid Waste. The second was the EPA Office of Water database, discussed in Section 2, which was derived from data collecting during development the effluent guidelines for landfills. The EPA Office of Water database includes characterization data for 35 landfills of various types. Twenty-three of these landfills could be conclusively identified according to type (21 MSW landfills and two commercial hazardous waste landfills). The remaining Office of Water landfills could be categorized as managing Subtitle D (either industrial or C&D) waste or Subtitle C hazardous waste, but it could not be determined whether they were captive to a specific industry or accepted waste on a commercial basis from multiple generating sources. Data from this latter set of landfills are included in the electronic database accompanying this report, but are not included in the summary statistics provided in the remainder of this section.

To locate data from state government sources, contact was initiated with cognizant agencies in all 50 states. In general, limited automated data, other than capacity summary data, were found. The summary table describing the leachate data collection programs in each state is presented in Appendix A. Data from two states, however, were available for combining into the LEACH 2000 database. The first data set, from the State of Florida, comprises leachate characterization data for 65 MSW landfills. The second data set represents 70 landfills from the State of Wisconsin. The Wisconsin data includes 39 MSW landfills, 18 paper mill landfills, 6 combustion ash landfills, and 7 landfills of other types.

In analyzing the Wisconsin data, certain patterns of statistical outliers were discovered. These patterns were consistent with intermittent misreporting of analytical units. Therefore, a detailed analysis was undertaken to identify and correct data points in the Wisconsin data suspected of having this problem. This analysis is described in detail in Appendix F. Separate data tables have been included in the LEACH 2000 database representing the original and adjusted Wisconsin data. The Wisconsin data included in the combined data table in LEACH 2000 and used in this report represent the adjusted data.

Another relevant characteristic of the Wisconsin data is that, for a number of landfills, it was possible to identify the date of first operation. The Wisconsin data, therefore, were instrumental in the analysis of temporal variability in fundamental leachate characteristics in MSW landfills presented in Sections 3.2.2 and 3.2.3.

3.2 Municipal Solid Waste Landfills

The discussion of MSW leachate and leaching processes in this report is more extensive than that for other types of landfills for several reasons. First, prior scientific review of MSW landfills has been extensive. Second, the data available for MSW landfills in the characterization database are more extensive than for any other type of landfill. Third, EPA has traditionally viewed the MSW landfill as the default mismanagement scenario for hazardous waste (e.g., in the TCLP analysis the leaching medium is intended to simulate those acids present in an MSW landfill), so leaching processes in these landfills are of particular interest. Finally, the discussion of leaching processes in MSW landfills provides a basis for the comparison of leachate from different types of landfills in Section 3.6.

Section 3.2.1 provides a general overview of the composition of MSW leachate, based primarily on the extensive data available in the characterization database. Later sections discuss both the circumstances under which these parameters are known to change in value and the significance of these parameters to accelerating or inhibiting the leaching of toxic constituents. Section 3.2.2 discusses temporal changes known to occur in a MSW landfill and how this affects the composition and properties of leachate generated over time. Section 3.2.3 isolates parameters which can be variable in MSW leachate and which are known to affect contaminant mobility.

3.2.1 Overall Composition of MSW Leachate

Municipal solid waste (MSW) landfills receive waste primarily from residential, commercial, and institutional sources. Some MSW landfills may receive quantities of construction and demolition debris, non-hazardous industrial waste, and even hazardous waste from household sources or other exempt small-quantity generators. The quantities of these types of waste, however, typically are small compared to the quantities of municipal waste managed. Several specific examples of MSW landfill operations may be found in Section 4 of this report (case studies 6, 9, 11, 15, and 18 through 22).

In part because of the large number of sources and resulting heterogenous nature of the waste, MSW leachate is a complex mixture of inorganic and organic constituents. The specific composition of MSW leachate also varies both spatially (within a single landfill and between landfills) as well as temporally. While research has identified some of the reasons for this variability, it is useful to first identify what some of these parameters are and the values that can be expected in landfill leachate. The data presented in Table 3-1, below, are from the more than 200 MSW landfills represented in the LEACH 2000 database.

As discussed in Section 3.1 above, although a large number of MSW landfills are represented, they do not necessarily constitute a statistically representative sample of MSW landfills by geographic region or any other criterion. Nevertheless, these MSW landfills do represent a variety of locations, ages, and other factors which are expected to result in variation between landfills. Such variation results from the many factors affecting leachate composition which will be discussed in Sections 3.2.2 and 3.2.3. Specifically, these and other sections focus on explaining the conditions wherein low, high, or median values will most likely be encountered.

The constituents included in Table 3-1 (and similar, subsequent tables for other types of landfills in other sections of this report) represent the parameters most frequently analyzed for in the

characterization data included in the LEACH database. They are not a complete set of all the constituents for which data are available in the database. Constituents not included in the tables have fewer samples from which to draw statistics than those constituents represented in the tables.

Table 3-1 organizes constituents into three categories: major physical/chemical parameters (e.g., pH, chemical oxygen demand (COD), major anions), trace inorganics (e.g., RCRA metals), and organics. The paragraphs below discuss the available characterization data for MSW landfills in each of these categories.

General Parameters

Parameters commonly analyzed in wastewaters are also commonly analyzed in MSW leachate. Unfortunately, data for other parameters known to be critical in leaching assessments, such as oxidation-reduction potential, are not well represented in the characterization data or the scientific literature. Conventional pollutants for which data are available include pH, alkalinity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), and common anions. Typical ranges for these pollutants cover several orders of magnitude even with a single landfill.

Trace Inorganics

The inorganics most frequently detected in MSW leachate are, in order of detection frequency: manganese, boron, barium, zinc, aluminum, nickel, arsenic, chromium, copper, and lead. These constituents were detected in more than 50 percent of the MSW landfill leachate samples.

Organics

Most organic compounds such as volatiles, semivolatiles, pesticides, PCBs, herbicides, and insecticides are detected in MSW landfill leachate with less frequency than other parameters such as metals. For example, a four-year, six landfill Waste Management Inc. study analyzed leachate samples for these parameters and found the following frequency of detection as follows:

- Volatiles: 10 percent
- Semivolatiles: 2 percent
- Pesticides: 3 percent
- PCBs: 0 percent
- Herbicides: 5 percent
- Insecticides: 6 percent.

These figures may be misleading with regard to certain specific organic compounds because they are an average of relatively frequently detected compounds and many other compounds detected rarely or not at all. Both the Waste Management study and the data compiled in Table 3-1 show that certain specific organic compounds are detected with some frequency. For example, in the LEACH 2000 database, acetone, benzene, ethylbenzene, phenol, and xylene are detected in greater than 50 percent of the samples. The Waste Management study similarly found toluene (79 percent), m- & p- cresol (79 percent), methyl ethyl ketone (71 percent), phenol (67 percent), acetone (63 percent), xylene (63 percent), and methylene chloride (58 percent) in greater than 50

percent of the samples. In general, however, organic compounds are detected much less frequently than metals in MSW leachate.

Table 3-1. Composition of MSW Landfill Leachate

Analyte	N	% Detected	5th %ile	10th %ile	Median	Mean	90th %ile	95th %ile
MAJOR PHYSICAL/CHEMICAL PARAMETERS (mg/L, except pH in Standard Units)								
Alkalinity	3,697	96.5	182	304	2,080	2,689	5,470	7,220
B.O.D.	4,645	94.2	7.05	16.9	536	2,548	7,276	11,800
Calcium	839	99.5	32.9	73.4	220	466	860	1,516
Chloride	4,392	99.4	19.2	43	704	5,024	2,800	4,610
C.O.D.	4,252	95.5	35	93	1,200	4,709	9,550	15,000
Cyanide	1,429	31.3	0.005	0.006	0.018	4.10	0.166	0.71
Fluoride	1,041	91.7	0.11	0.15	0.4	6.93	1.9	14.9
Iron	4,284	98.0	0.31	0.97	17.0	308	259	530
Magnesium	829	99.8	13	25	155	511	320	430
Nitrogen	3,482	93.1	0.45	1.2	145	7,367	625	901
pH	6,965	100.0	5.88	6.20	7	7.05	7.94	8.29
Sodium	2,321	98.5	18	49	539	2,290	1,910	3,010
Sulfate	2,930	87.6	6	11	92.7	314	514	1,000
T.O.C.	1,444	99.6	8.6	21	282	1,534	3,850	7,270
TRACE INORGANICS (µg/L)								
Aluminum	366	86.1	73	160	800	15,046	24,700	107,000
Antimony	710	25.5	3	4	13	70.0	190	360
Arsenic	2,444	71.1	4	6	20	441	100	260
Barium	1,779	93.4	50	84	405	866	1,700	2,800
Beryllium	653	11.2	0.3	0.5	4	39.5	55	143
Boron	764	96.5	190	490	4,500	87,541	16,000	27,000
Cadmium	2,351	31.5	0.5	1	10	28.3	79	110
Chromium	2,776	63.0	9	10	51	235	341	592
Copper	2,064	57.1	7.4	10	33	139	200	384
Lead	2,539	50.2	2	4	21	133	250	500
Manganese	2,371	97.4	51	99	744	6,076	15,000	37,000
Mercury	2,078	18.0	0.09	0.14	0.59	7.15	4.6	16
Nickel	1,889	80.9	20	30	120	679	489	740
Selenium	1,754	18.2	1	1.7	10	58.5	180	310
Silver	1,830	17.8	1	2	11.3	53.7	56	110
Thallium	632	12.2	1	2	15	149	516	815
Zinc	2,282	89.6	14	24	160	5,103	2,300	7,300
ORGANICS (µg/L)								
1,1-Dichloroethane	1,768	39.9	1.5	2.2	19	66.1	122	195
1,1-Dichloroethene	1,155	1.9	0.6	1	15.5	134	176	251
Acenaphthene	677	8.7	1	1	6.15	11.22	32	55
Acetone	815	61.7	16	33	770	3,299	9,200	12,000
Benzene	2,169	52.3	1	1.7	6.69	32.5	51	117
Chloroethane	1,771	19.9	2	3	12	24.1	50	100
Ethylbenzene	1,897	65.8	2	4.43	34	1,502	150	290
Methyl Isobutyl Ketone	844	44.4	4	10	120	3,631	970	1,740
Naphthalene	1,190	46.7	2.40	3.90	16.6	48.1	120	256
Phenol	1,624	71.9	10	17	190	45,900	4,100	34,000
Trichloroethylene	1,845	20.6	0.604	1	7.51	22.9	53	86.4
Vinyl Chloride	1,952	20.7	0.9	1.1	6.6	2,409	70	542
Xylene	2,285	68.0	3	5.8	53.3	1,452	239	390

Source: Characterization data from the more than 200 MSW landfills included in the LEACH 2000 database.

3.2.2 Temporal Variability in MSW Landfill Leachate

Stages of a MSW Landfill

The quality and rate of leachate generation at a landfill changes over time. This is caused by changes in the dimensions of the waste inside the landfill, its potential for oxidation or degradation, etc. These changes in leachate quality in turn affect the mobility of toxicants.

The municipal waste landfill has been described as an anaerobic microbial process during much of its active life, a process which can be modeled or conceptualized as a batch digester with inputs of refuse and moisture and outputs of gas and leachate. Pohland (1986) has described the municipal waste landfill in five phases.

- Phase I: Initial Adjustment. This period represents the beginning of the operating life of the landfill where refuse is initially placed and moisture enters the cell.
- Phase II: Transition. This period represents the beginning of leachate generation (i.e., the available moisture exceeds the capacity of the surrounding soils or refuse itself). The landfill changes from aerobic conditions to anaerobic microbial stabilization. This is due to the presence of carbon dioxide rather than oxygen in surrounding gas. With this change from aerobic to anaerobic conditions, critical electron accepting molecules change from oxygen to nitrates and sulfates and an overall reducing environment is encountered. The increased moisture also enhances microbial activity. Metabolic by-products such as volatile organic fatty acids and alcohols appear in the leachate and increase its organic strength (Farquhar, 1989).
- Phase III: Acid Formation. Volatile organic fatty acids become predominant in the leachate, with the continuation of conditions described for Phase II. Nutrients such as nitrogen and phosphorous are released and utilized in support of the growth of biomass. Decreases in pH are observed in the leachate as a result of the presence of the organic acids.
- Phase IV: Methane Formation (or methanogenic). Nutrients continue to be consumed and intermediates such as volatile organic fatty acids are converted to methane and carbon dioxide. This gives several results. First, the leachate organic strength is reduced and gas generation increases. As a result of the decrease in fatty acids, the pH changes; the pH becomes representative of a bicarbonate buffered system rather than the organic acid buffered system. The landfill continues to represent a reducing environment, with oxidation-reduction potential at the lowest level.

The methanogenic phase of a MSW landfill is expected to be best demonstrated under the following conditions (Ehrig, 1983): Moisture content $\geq 50\%$; Temperature $> 15^{\circ}\text{C}$ (60°F); Good buffering capacity of leachate: alkalinity 2,000 mg/L as CaCO_3 , and ratio of volatile fatty acids to alkalinity ≤ 0.8

- Phase V: Final Maturation. In this phase, nutrient availability may become limiting due to the consumption of the readily available organic constituents in the waste and leachate; microbially resistant organic materials may be slowly converted. As a result of the decrease in activity, measurable gas production decreases. Oxygen and oxidized species may reappear with a corresponding increase in oxidation-reduction potential.

Significance of Phases Towards Leaching

While five steps in an MSW landfill life are listed above, anaerobic activity is only present in two of them (phases III and IV). These are the times of a landfill's life which are most dynamic, and therefore of interest to many researchers. The phases are chronological but the corresponding length of time for each stage is site-specific. However, researchers (Ehrig, 1983; Farquhar, 1989) have generally found this period to be relatively short (<10 years or even as little as several months) as compared to the length of time that the landfill is actively accepting wastes (e.g., 20 years or more) or generating leachate (many years following closure). These site-specific factors influencing the time for these stages to proceed include landfilling procedures, the nature of the wastes, the quantity of moisture entering the landfill, and closure conditions (Pohland, 1986). Additionally, individual cells within a landfill may be at different stages and exhibit different phenomenon, such that the overall landfill becomes a complex characterization of the above processes.

The different stages of activity within a landfill result in differences in certain indicator parameters. For example, the presence of organic fatty acids and varying values of oxidation-reduction potential were described in general terms for these different stages. The variation of these parameters are discussed below. Not only are these parameters indicative of conditions within a landfill, but they result in differences in mobility, precipitation, and speciation of metals in the waste and leachate. Pohland (1986) lists many factors that are associated with the different stages listed above. Of particular interest are parameter ratios, such as the ratio of BOD to TOC, for which the value of the ratio changes as do values of the parameters themselves.

Some of these factors, such as changes in pH, are well-studied factors which are known to affect the leaching behavior of metals such as lead. Other factors, such as total solids, may indeed be reflective of the different stages in landfill life but have little impact on the mobility of contaminants.

3.2.3 Factors Affecting Contaminant Mobility

Researchers have historically analyzed MSW landfill leachate for a wide variety of parameters, and a wide body of literature exists with these results. However, their reasons for research have been equally varied, including wastewater treatment concerns and methane gas generation concerns. While these areas of study can supplement and provide critical input to work regarding contaminant leaching processes, it also means that parameters that are often presented in the literature may or may not have relevance to contaminant leaching. Unfortunately, because leaching fundamentals is such a complex topic it is difficult or impractical to conclude that a given parameter is 'unimportant.' Nevertheless, this section attempts to isolate several parameters that are known or suspected of the most significant affects of the mobility for toxic metals and other contaminants of concern to human health and the environment.

The effect of extract properties upon contaminant mobility has been researched for a wide variety of wastes and even for industrial processes such as liquid-liquid extraction. A number of factors affect the degree of mobilization or fixation of contaminants in the waste. Usually several factors are in operation simultaneously (e.g., in the case of microbial activity in MSW leachate). Conner (1990) listed many factors in their application to hazardous waste stabilization processes; not all of these factors are relevant to environmental leaching phenomena. Other researchers have suggested additional factors. Some of these major factors as applied to MSW landfill conditions include the following:

- pH. The solubility of metal species as a function of pH is well studied in the physical sciences as well as the waste treatment literature. For example, when studying a single species such as lead hydroxide, the concentration of lead in solution is lowest at pH 9.5 (Conner, 1990).
- Redox potential (oxidation reduction potential). The presence of strong oxidants or reductants can change the valence state of metals such as chromium and arsenic. This in turn affects their speciation and their solubility. High values indicate an oxidizing environment; low or negative values represent a reducing environment. Chemical species are often stable in one area of pH and redox potential; changes in one or both of these variables may result in a different species being stable and creating a driving force for conversion between the species (Conner, 1990). Redox also affects the presence of anionic species such as sulfate/sulfite, which differ in their solubilities towards metals.
- Organic leachant composition (e.g., total volatile acids). Leachants such as EDTA and acetic acid are generally believed to be more aggressive than distilled water (Van der Sloot, 1997). This is due to the presence of acid as well as its buffering capacity to counter the effects of alkalinity and hold the pH at this lower value. Metal species may be complexed with dissolved organic carbon and affect mobility.
- Biological Oxygen Demand
- Chemical Oxygen Demand
- Ratio of Biological Oxygen Demand to Chemical Oxygen Demand
- Total alkalinity
- Sulfate and sulfide. The presence of anionic species such as sulfate and sulfite differ in their solubilities towards metals.

These factors are discussed in greater detail below. These are the parameters which are known to be present in leachate, and which also affect mobility of contaminants. Field leachate is a complex mixture of parameters and while some factors are well studied and their importance has previously been isolated (such as some of these above factors), other parameters present may exert synergistic effects, no effects, or even countering effects towards contaminant leaching behavior.

Additional parameters are present in landfill leachate at levels different than ambient conditions, or change over time, but their effect on contaminant leaching is not well known or not well studied. Such factors, listed below but could include others, are not extensively discussed in this report.

- Conductivity. An increase in conductivity indicates an increase in ionic strength of the solution. For some ionic species, the effect is an increase in solution concentration (Frampton, 1998).
- Total Organic Carbon
- Ratio of Chemical Oxygen Demand to Total Organic Carbon
- Total Kjeldahl Nitrogen
- Nitrate
- Ammonia
- Ratio of Ammonia to Total Kjeldahl Nitrogen
- Total phosphate
- Total solids
- Chloride. Chloride may form stable soluble complexes with certain metals, such as cadmium.

pH

In the literature, low leachate pH has been associated with increased microbial activity and therefore are an indication of additional processes occurring: organic acid formation, increases in alkalinity, changes in oxidation-reduction potential, etc. Higher values of pH (i.e., greater than 7) are generally associated with more mature landfills with less bioactivity.

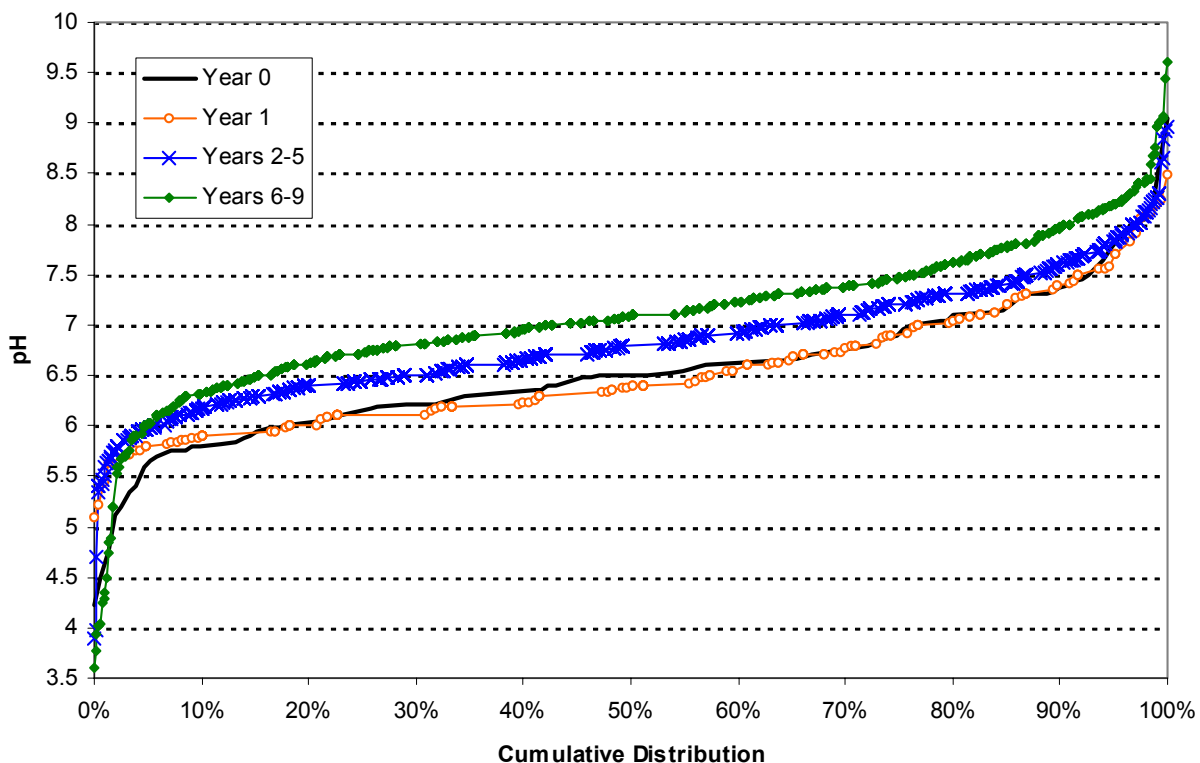
Poland (1986) identifies an early stage of a landfill where pH is low due to acid formation (e.g., 4.7 to 7.7), rising above 7 in later stages. Data from Ehrig (1983) support this assessment. Specifically, pH values between 4.5 and 6 were most often found in the first two years of landfill operation; after approximately two years the lowest pH values were no lower than 6. The highest pH values from Ehrig (1983) were 8 to 9.

Data from Farquhar (1989) also show that relatively young landfills have lower pH. Leachate from landfills of less than 5 years exhibit typical pH of 5 to 6; this rises to 7.5 after 20 years. Time series data from a single cell in a South African landfill shows a similar trend, with a value of 5.9 after five months increasing to 7.8 after 42 months (Ross, 1990).

MSW landfill leachate data from the LEACH 2000 database also show a correlation between pH and landfill age. Specifically, the Wisconsin data included in the database allow identification of landfill age. Using data for Wisconsin MSW landfills, Figure 3-1 presents cumulative frequency distributions of pH for MSW landfills in various age categories. The median (50th percentile) pH shifts upwards for landfills of age 2 and older. Approximately 20 percent of landfills less than 2 years old had leachate pH less than 6. However, for landfills between 2 and 9 years old only approximately 5 percent of landfills exhibit pH less than this value. The frequency of lower pH (i.e., pH of 5 or lower) is very infrequent for any landfill age (a maximum of approximately 3 percent), and conclusions regarding the effect of landfill age at this low range are difficult to make.

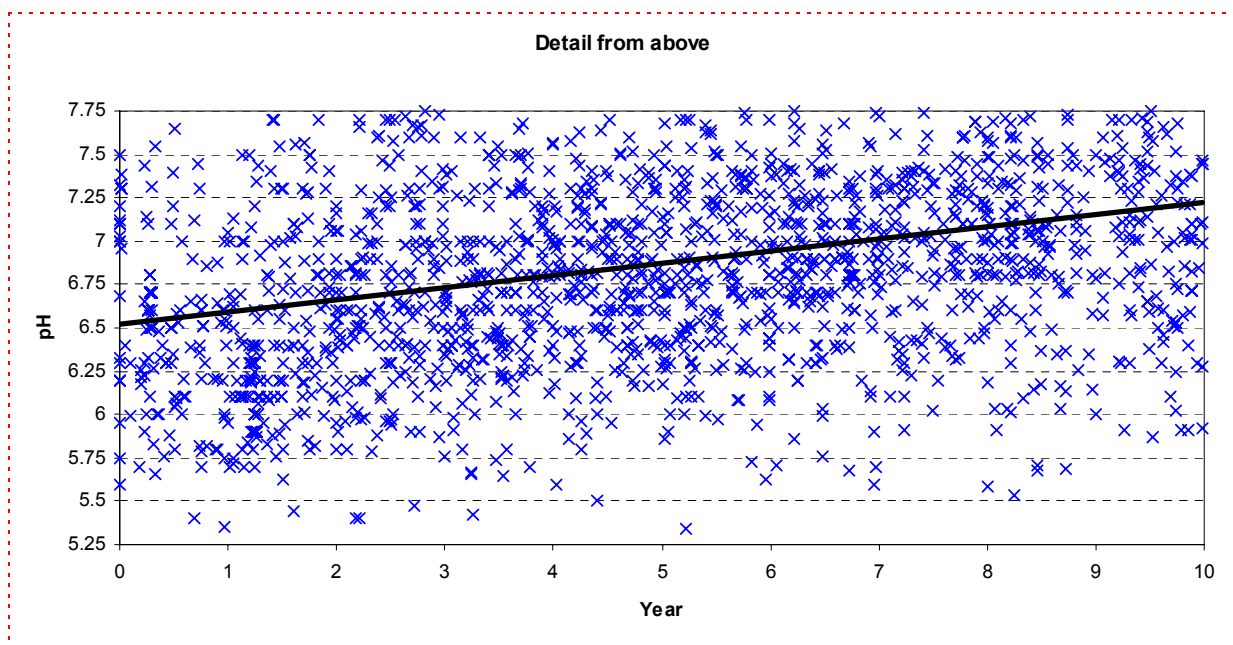
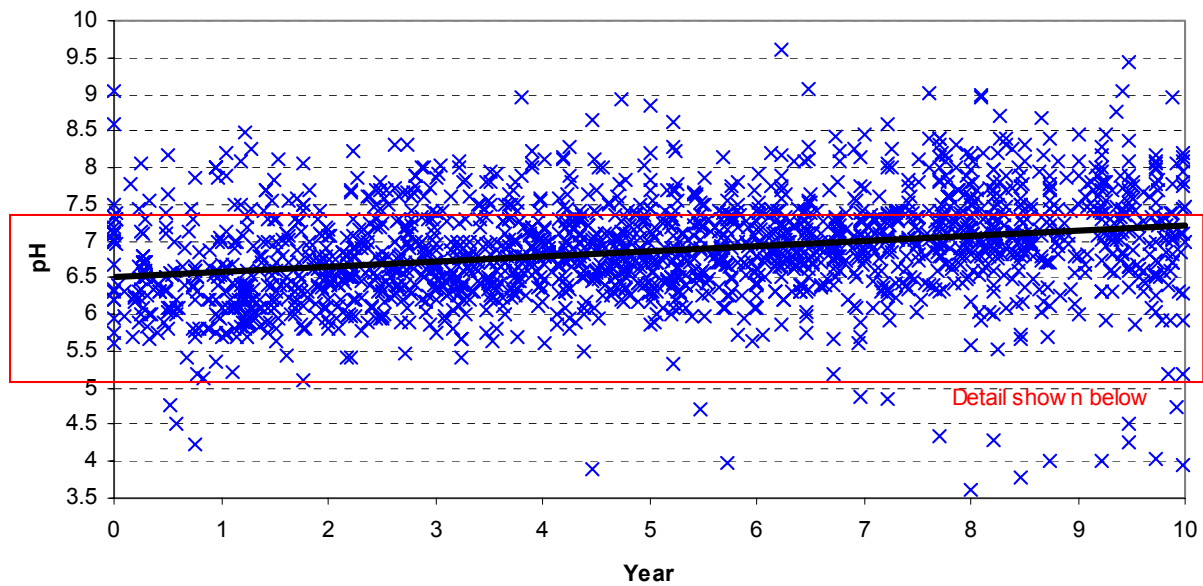
At the other pH extreme, pH values above 8 were most common in the landfills of age 6 to 9 years according to the Wisconsin data (approximately 10 percent of the cases). For the remaining landfills (aged 5 years or less), approximately 5 percent of the landfills had pH values above 8.

Figure 3-1. Cumulative Frequency of pH in Wisconsin MSW Landfills by Age Group



Using the same data, it is possible to perform regression analysis of pH versus age to further examine the relationship between pH and landfill age. While the relationship does not explain all of the observed variation in pH, the trend is statistically significant at the 1 percent level. Figure 3-2 shows the scatter plot of pH versus age for the Wisconsin MSW landfills with the regression line indicated. Further examination of Figure 3-2 further supports the observation that low pH is more frequent in young landfills. Observations below pH of 6 become less frequent for landfills older than approximately 5 years (see the detail expanded in Figure 3-2).

Figure 3-2. pH Observed in Wisconsin MSW Landfills by Age



R squared = 0.08
Significant at 1%

A review of time series data at individual landfills appears to indicate that the trends seen in the overall data hold true for many individual landfills, but not all. Figures 3-3 and 3-4 present trend lines based on regression analysis of pH versus age for each of the individual landfills represented in the Wisconsin data. More than half of the individual landfills display statistically significant increasing trends (Figure 3-3). Statistically significant trends could not be found for three landfills. The other landfills displayed trends that were decreasing or variable (Figure 3-4)

Figure 3-3. pH Trends for Individual Landfills (increasing)

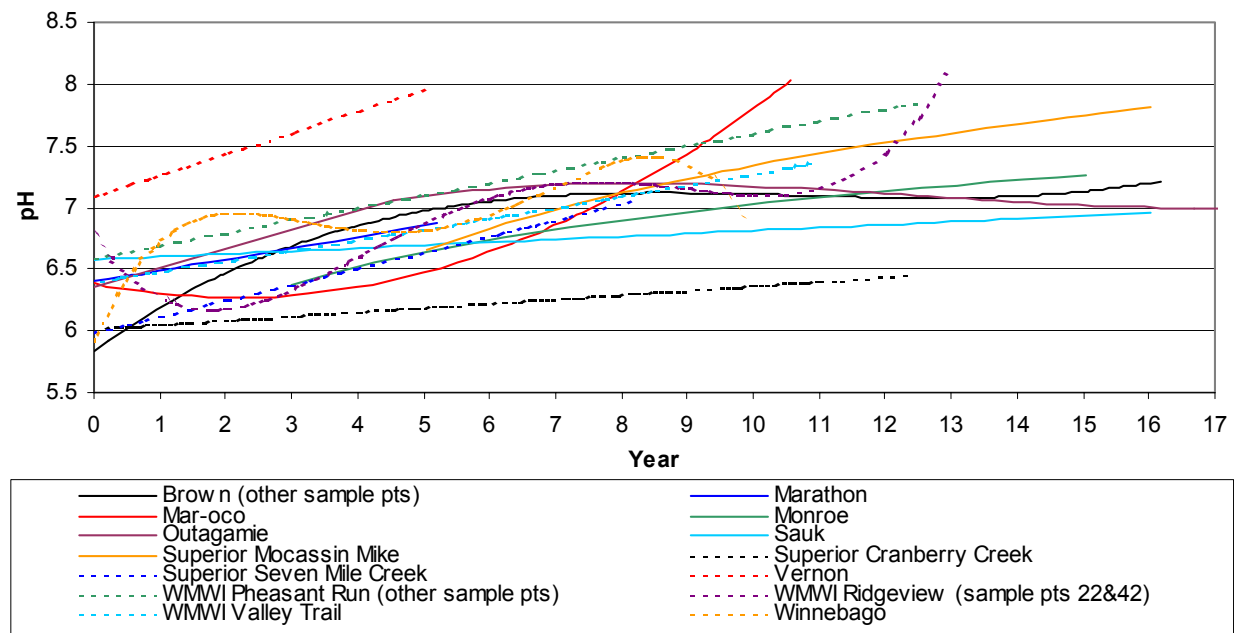
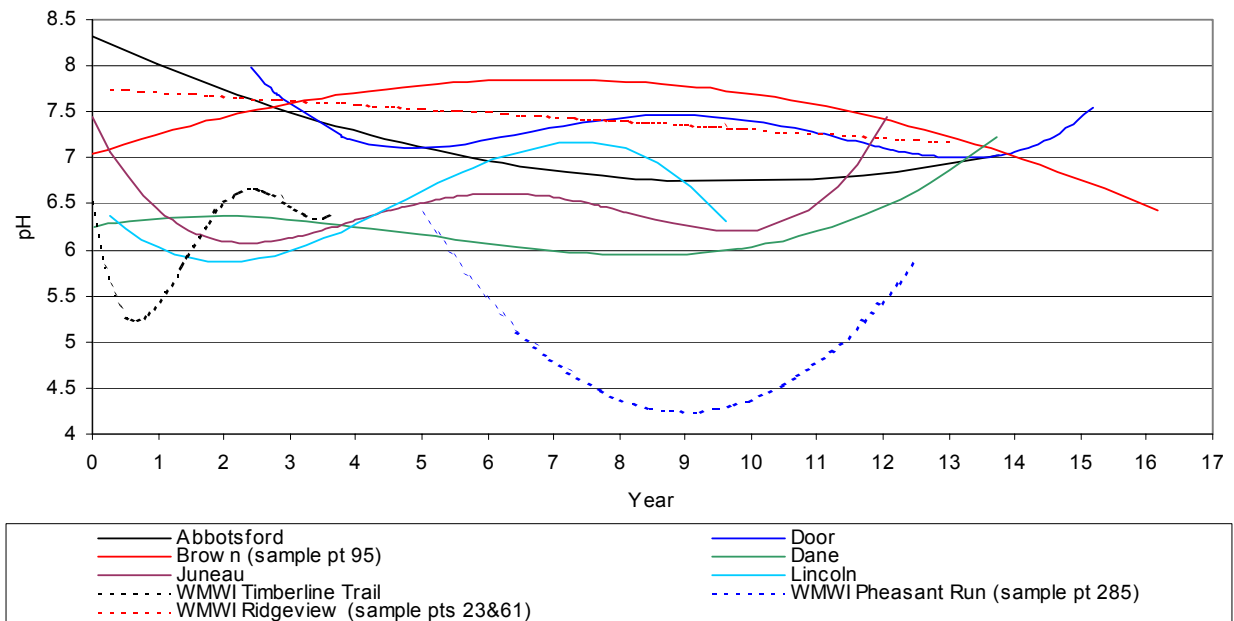


Figure 3-4. pH Trends for Individual Landfills (decreasing or varying)



Redox Potential and Sulfate

While a theoretically important parameter in identifying the stability of individual metal species, and therefore mobility, redox potential is not often reported in the literature. Further, the analytical measurement can be prone to significant error. In one study (Chian, 1977), analysis for redox potential was made immediately following collection, and then frequently for a twelve day period. After 24 hours the measurement was 100 mV higher (i.e., representing a more oxidizing environment) than immediately following sampling, even under refrigerated conditions. Redox potential showed the largest dependence on analysis time of any of the parameters measured. This study shows that reports of redox potential in the literature may or may not be reflective of the actual conditions in the leachate depending on whether the analysis occurs in the field or following delivery to a laboratory.

One study (Chian, 1977) identified redox potential as a function of landfill age. The results were plotted with pH and showed that as pH increased, redox potential increased. As discussed above, different researchers have found that pH rises slightly as a landfill ages. During the early years of a landfill life (< 2 years), redox potential ranges from -200 to 150 mV. Later (5 to 15 years), the upper end of the range is still 150 mV while the range has narrowed somewhat. Low values of redox potential have been cited as due to a high degree of anaerobiosis in the landfill, while higher readings reflect a steady-state situation. Low redox potential values are associated with reducing conditions, high values with oxidizing conditions.

These data are consistent with information from Pohland (1986). In the second phase of a landfill (initial formation of leachate), the redox potential ranges from 40 to 80 mV. The third phase (acid formation) and fourth phase (gas formation) show the lowest values of redox potential: -240 to 80 in Phase III and -240 to -70 in Phase IV. Redox potential in Phase V is reported as 97 to 163.

Based on these two studies by Pohland (1986) and Chian (1977), low redox values (reducing conditions) are most likely to be present during the acid generation and methane formation phases of a landfill, with redox potential reaching its lowest value in the methane generation phase. Therefore, in cases where such redox data are not available it may be possible to extrapolate, qualitatively, what these conditions may be based on other properties indicative of Phase II and Phase III behavior.

Sulfate concentration is one possible parameter to use as a surrogate. Chian (1977) presents sulfate concentration data as a function of landfill age, plotted as the ratio sulfate to chloride concentration. This trend is compared to trends in pH and redox potential over time. As the landfill ages, the sulfate/chloride ratio decreases, redox potential increases, and pH increases. The decrease in the sulfate/chloride ratio is attributed to anaerobic conditions where sulfate is reduced to sulfide. There is an inverse correlation between redox potential and sulfate concentration which is explained by Chian (1977) as low ORP readings (reducing conditions) correspond to falling sulfate levels. In addition to its indication of reducing conditions, the presence of sulfides may result in lower metal solubilities. Species of cadmium, copper, lead, mercury, nickel, and zinc are insoluble in their sulfide form (Conner, 1990). Conversely, sulfate forms are much more soluble.

Ehrig (1983) has presented data for sulfate concentration as a function of landfill age in laboratory scale experiments, where the acid formation and methane fermentation stages are condensed to a period of days rather than years, as well as from an operating landfill. For the laboratory scale study, in comparing these results to other parameters, the highest sulfate concentrations were present early, followed by a drop in concentration for the remainder of the study period. The time of the drop corresponded to a rise in pH and lagged the fall in concentration of COD and BOD (as discussed below). These results, therefore, are similar to the Chian (1977) results that show decreasing sulfate levels over time and increasing pH over time. Because sulfur is still present in the system, the sulfur would likely be converted to sulfide as sulfate concentrations fall.

The operating landfill data presented in Ehrig (1983) suggest similar findings. Sulfate concentration decreases from approximately 1,300 mg/L at the beginning of the study (when the landfill is 1½ years old) to less than 100 mg/L after 6½ years. The fall in sulfate concentrations parallel the fall in COD and BOD levels, and a rise in pH.

Similar results are available from Farquhar (1989) which summarizes data from previous studies, showing the effect of landfill age on parameters including sulfate; the data were presented in tabular format grouping the landfill ages into five or ten year increments: 0 to 5 years, 5 to 10 years, 10 to 20 years, and greater than 20 years. As expected, landfills greater than 20 years had the lowest levels of sulfate (<100 mg/L). Conversely, these parameters exhibited the highest levels in the range of 0 to 5 years (500 to 2,000 mg/L) and decreasing in the range of 5 to 10 years (200 to 1,000 mg/L).

Organic Content: Overview

The organic content of leachate is measurable by several parameters, including volatile fatty acids, chemical oxygen demand (COD), and biological oxygen demand (BOD). Volatile fatty acids (e.g., acetic acid) are the product of biological activity. Chemical oxygen demand is a test to quantify the oxidizable contents of a wastewater and represents the ultimate value of the oxygen that the wastewater could consume in oxidizing species that are present as reduced species. Biological oxygen demand is indicative of the degree to which the contents of the water is amenable to biological activity. It is measured by adding oxygen and bacteria and allowing equilibration for five days. The ratio of BOD to COD can not be greater than 1; values close to 1 indicate that biological degradation is favorable while values much less than 1 indicate that some oxidizable material is not biodegradable (Stephenson, 1998).

Each of these parameters are indicator parameters, which do not measure any one species or compound but a class of compounds.

BOD and COD

The measurement of the ratio of BOD to COD in landfill leachate, as well as absolute values of these parameters, is provided by several researchers. Ehrig (1983) measures these parameters in landfills aged up to 7 years. In one landfill, these parameters behaved similarly such that elevated levels of COD generally corresponded to instances of elevated levels of BOD, and elevated levels of the ratio between BOD and COD. Specifically, these levels were elevated and stayed at these levels from year 1½ (initial measurement) until year 3, with the exception of a

sharp dip and rise shortly after measurements began. Following year 3 there was a gradual decrease in the values of these parameters to year 6 ½ when the activity was at its lowest. Interestingly, the behavior of pH in this same period of time was a gradual increase from 6 to approximately 8.

The results of the single landfill study by Ehrig (1983) correlate well to results from many landfills presented in the same paper as generated using data from a variety of previous studies (mostly from studies initiated in the United States) and from data from landfills in Germany. The effect of age on COD measurements shows a very uniform steady state concentration of COD after year 8 (approximately 3,000 to 5,000 mg/L). Prior to this year the data are much more scattered with many of the values higher than this (as consistent with the single landfill study) but several of the values lower (ranging from 100 to 40,000). Similar results are obtained in a laboratory scale experiment, where concentrations of BOD and COD are initially high (approximately 10,000 to 15,000 mg/L for BOD and 15,000 to 25,000 for COD) but, together with the BOD to COD ratio, drop following a rise in pH.

The findings of Ehrig (1983) are consistent with the data presented by Pohland (1986). Pohland (1983) indicated that the ratio of BOD to COD increases during Phases II and III of the landfill life (transition and acid formation), then drops in later phases (e.g., gas production). Absolute values of biological oxygen demand and chemical oxygen demand have similar behavior, in that these values increase in Phases II and III and drop in later phases.

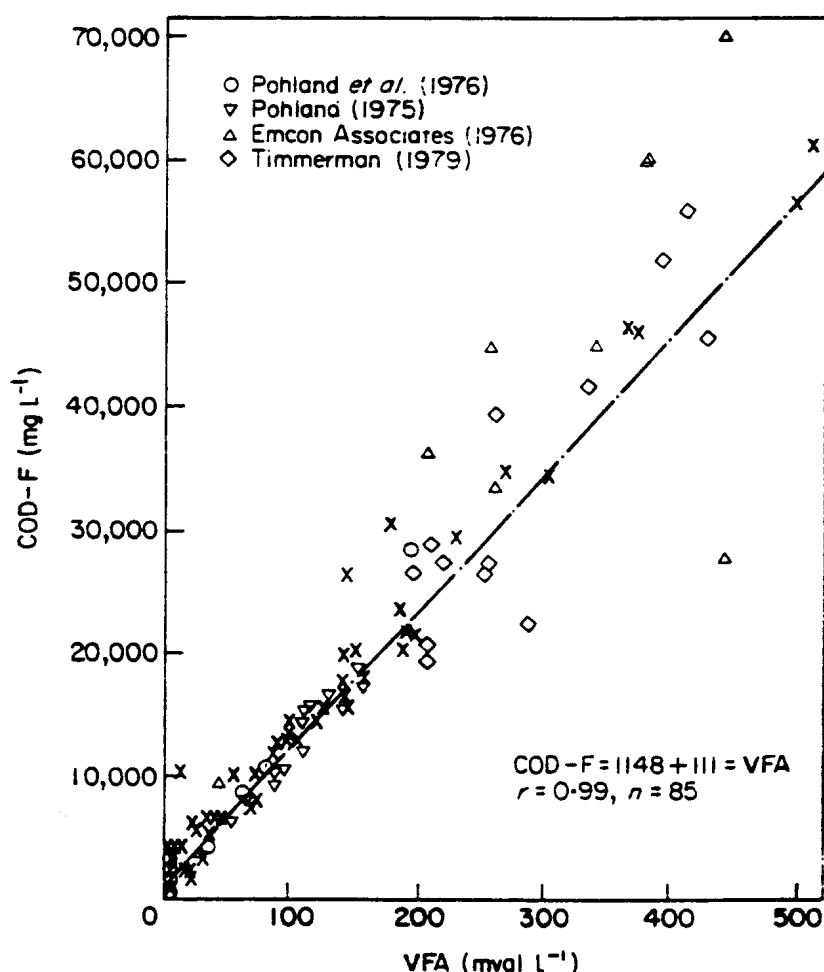
Similar results are available from Farquhar (1989) which summarizes data from previous studies, showing the effect of landfill age on parameters such as COD and BOD; the data were presented in tabular format grouping the landfill ages into five or ten year increments: 0 to 5 years, 5 to 10 years, 10 to 20 years, and greater than 20 years. As expected, landfills greater than 20 years had the lowest levels of BOD and COD. Conversely, these parameters exhibited the highest levels in the range of 0 to 5 years and decreasing in the range of 5 to 10 years.

While the above sources suggest that relatively young municipal waste landfills have higher levels of BOD, COD, and BOD/COD ratios, conflicting data are available from Waste Management's study of leachate generated from six of its municipal waste landfills, each varying in age and characteristics. In comparing the average values of organic indicator parameters (BOD, TOC, and COD) to the start date of the landfill, no clear trends are apparent. Average levels of COD and BOD are highest in the oldest landfill, a finding in contradiction to the Farquhar (1989) and Ehrig (1983) results. However, average values from the Waste Management data are relatively low in comparison to the data from these two previous papers. The average values of COD from Waste Management ranged from 227 to 4,645 mg/L; Ehrig (1983) identifies the range of 3,000 to 5,000 mg/L as typical of long term steady state conditions.

Volatile Fatty Acids and COD

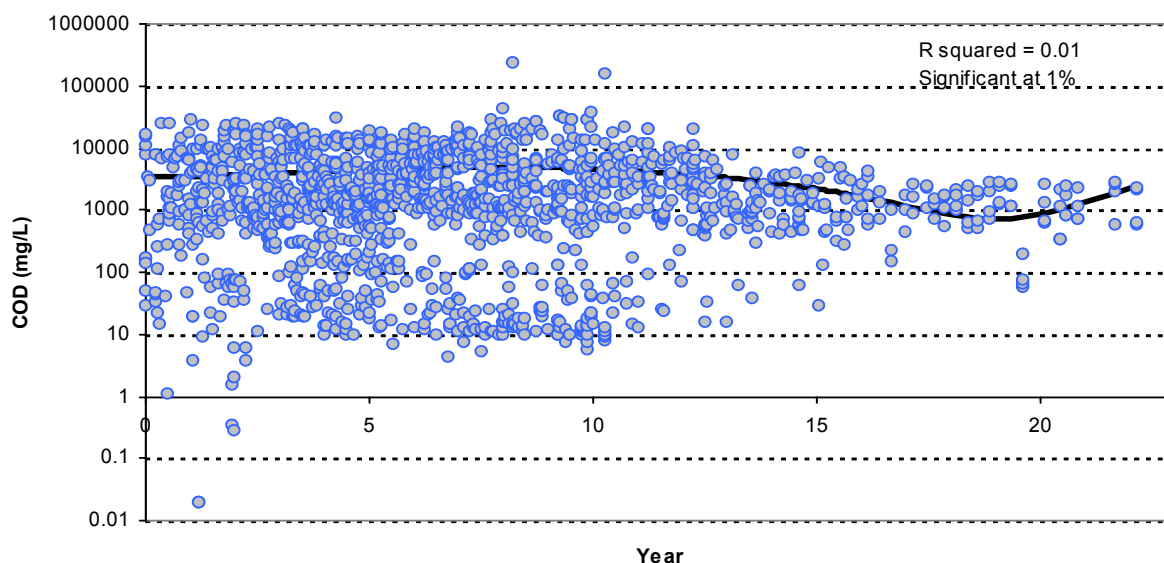
The correlation of volatile fatty acid concentration to COD concentration was also demonstrated by Ehrig (1983), who used the result to theorize that the volatile fatty acids are responsible for the chemical oxygen demand (see Figure 3-5). Specifically, samples with low COD also had low concentrations of volatile fatty acids, a correlation which was generally linear over a range of 0 to COD of 60,000 mg/L.

Figure 3-5. Relationship between VFA and COD in Landfill Leachate (from Ehrig, 1984)



Information from Pohland (1986) support this correlation to an extent. Specifically, COD concentration, TOC concentration, and volatile fatty acid concentrations all increase during the acid formation phase of the landfill. During the methane fermentation phase, the volatile fatty acid concentration decreases because of its bioconversion to methane; COD and TOC similarly decrease. These matching trends are due to the overlap of volatile acids as analytically measured by each of these three parameters. However, later in the life of a landfill volatile fatty acids are essentially absent. This decline in COD is confirmed using time series data from Wisconsin (Figure 3-6) however these data do not proceed long enough (i.e., beyond 20 years) to evaluated hypotheses regarding the later stages of landfill life. COD and TOC measurements, while low, are non-zero due to the presence of higher molecular weight residual organics. Together, the Ehrig (1983) and Pohland (1986) data imply that high values of COD are the result of high values of volatile fatty acids, but lower values of COD may reflect negligible concentrations of volatile fatty acids.

Figure 3-6. COD Observed in Wisconsin MSW Landfills by Age



Characterization of volatile fatty acids has been conducted by several researchers and summarized by Frampton (1998). During the acid generation phase, volatile fatty acids can comprise up to 87 percent of total organic carbon in MSW landfill leachate. Following this period, other sources of organic carbon dominate including fulvic acid, humic acid, and high molecular weight (>10,000) organic compounds.

The significance of volatile fatty acids towards contaminant leaching has been the focus of leaching test development, including which acids should be incorporated into the test fluid and their effects on leaching. Volatile fatty acids such as acetic acid can form stable (and soluble) complexes with metal cations (Frampton, 1998). In contrast, when analyzing for metals in a mixture of low molecular weight (volatile fatty acids) and higher molecular weight (>500) organic molecules following ultrafiltration, the metals magnesium, calcium, and zinc were associated with the low molecular weight organic fraction (Chian, 1977). This shows that volatile fatty acids may be more significant than higher molecular weight species in mobilizing metals.

Alkalinity

Alkalinity reflects the acid neutralizing capacity of an aqueous solution, measured as the equivalent sum of the bases that are titratable with strong acid to an equivalence point. It represents the sum of all such bases, such as hydroxides (OH^-), carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), and other anions that may be present to react with excess protons (H^+) (Stumm, 1981). Therefore, alkalinity is used as an indication of the buffering capacity and the ability of a solution to maintain a pH, rather than to identify the exact anionic species in a solution.

The general behavior of alkalinity in a landfill over time is expressed by Pohland (1983). The highest levels of alkalinity are found in the acid formation phase of the landfill, Phase III. This is due to the formation of volatile acid which results in dissolution of bicarbonate. As volatile acids

are removed due to their conversion to methane and carbon dioxide, residual alkalinity determines the resulting pH of the system. If alkalinity is relatively high the pH of the system becomes controlled by the anions contributing to alkalinity; low alkalinity makes the system more susceptible to changes affecting pH.

Ehrig (1983) also presents information regarding alkalinity. The ratio of volatile fatty acid concentration to alkalinity is presented, and observed that gas production is initiated when the ratio drops below 0.8 (i.e., the landfill enters Phase IV), which occurred in the sixth year of landfill activity. Unfortunately, this paper does not present the actual values of alkalinity as well. As shown above, volatile fatty acid concentration drops in Phase IV, but based on data by Farquhar (1989) and the above discussion by Pohland (1983) alkalinity decreases over time as well. High pH values (i.e., greater than 7) were also correlated with low ratios of volatile fatty acids to alkalinity, showing that high levels of volatile fatty acids are associated with low pH.

Farquhar (1989) presents information regarding alkalinity as a function of time (years of landfill operation). Values are highest (10,000 to 15,000 mg/L) in the period 0 to 5 years. Values steadily decrease over the ranges 5 to 10 years, 10 to 20 years, and greater than 20 years where the value is less than 500 mg/L. Data reflecting the first 10 years of MSW landfill operations from Wisconsin do not indicate any significant decline in alkalinity but this pattern may be more visible in later stages of landfill development.

This decrease in alkalinity over time may be the result of simple mass balance effects: additional alkalinity is no longer generated by bioactivity, and it is removed continuously in leachate. Therefore its concentration in leachate decreases.

Summary of Significant Findings for Indicator Parameters in MSW Landfill Leachate

Many researchers have found temporal differences for certain parameters present in MSW landfill leachate. These findings are summarized in Table 3-2 and reflect the body of literature discussed above. Some of these parameters may or may not have a direct affect on contaminant leaching. For example, high COD by itself may not significantly affect mobility. However, high COD levels are indicative of the acid generation phase of an MSW landfill where many different effects are happening simultaneously. One or a combination of these other parameters, however, may be indicative of contaminant mobility.

Table 3-2. Behavior of Indicator Parameters in MSW Landfill Leachate: Summary

Parameter	Result
pH	Initially low (5 to 6) due to the presence of organic acids forming during biodegradation. As these acids are removed by additional bioprocesses and converted to gas, pH rises slightly (to 8) to reflect new equilibrium conditions by residual alkalinity.
Redox potential	<p>Lowest during the acid generation phase; values of -200 mV are encountered (reflective of reducing conditions). These levels rise slightly during gas production and remain above zero for the remainder of landfill life.</p> <p>Sulfate concentration may be a surrogate indicator of redox potential if redox potential is not measured. Sulfate concentrations decrease over time from up to 2,000 to <100 mg/L; they convert to sulfides under the reducing conditions of the acid generation phase. Alternatively, the measurements can be used in conjunction to assess bioactivity.</p>
BOD and COD	Indicative of bioactivity. These parameters typically display a peaking behavior (initially low, rising, then low. High levels of each parameter indicate acid production; during gas production the levels fall. Additionally, the ratio of BOD to COD is indicative. High ratios indicate organic acid production, where most of the organic matter is biologically active. This ratio also exhibits peaking behavior.
Volatile Fatty Acids and COD	Volatile fatty acids have been shown to be a significant source of COD in MSW landfill leachate. Their presence demonstrates biological activity (acid formation) in MSW landfills. Other sources contribute to COD such as nonbiodegradable organic material.
Alkalinity	Highest during acid formation phase; bioactivity creates species contributing to acid content (e.g., formation of organic acids) and alkalinity (e.g., formation of bisulfide ion); alkalinity is also increased by acids solubilizing carbonate ion (which contributes to alkalinity). Alkalinity drops over time, perhaps due to the elimination of acid generation and subsequent 'washing out' of the ions.

3.3 Construction and Demolition Debris Landfills

Construction and demolition debris (C&D) landfills are less studied in the literature than municipal waste landfills. Based on the available literature, however, the cycle of a MSW landfill (e.g., acid formation, methane fermentation) may occur with less intensity or not at all in a C&D landfill. Section 3.3.1 provides a general overview of the composition of C&D landfill leachate based on the data available in the LEACH 2000 database. Section 3.3.2 discusses the information available on temporal changes in C&D landfill environments.

3.3.1 Overall Composition of C&D Landfill Leachate

C&D landfills, in general, receive materials associated with land clearing (soil, rock, trees), exterior structure demolition (concrete and asphalt rubble, roofing, brick), interior structure demolition (painted wallboard, framing, piping), and similar materials (Townsend, 1998). Two specific examples of C&D landfill operations may be found in Section 4 of this report (case studies 8 and 13). Section 4 also includes an example of a landfill receiving a mixture of MSW and C&D wastes (case study 17).

The data presented in Table 3-3, below are from the 22 C&D landfills represented in the LEACH 2000 database. As discussed in Section 3.1 above, these landfills do not necessarily constitute a statistically representative sample of C&D landfills by geographic region or any other criterion. As with the MSW landfill leachate data presented in Table 3-1, the constituents included in Table 3-3 represent the parameters most frequently analyzed for in the characterization data included in the database. Constituents are organized into three categories: major physical/chemical parameters, trace inorganics, and organics. The paragraphs below discuss the data for C&D landfill leachate in each of these categories.

General Parameters

For C&D landfills, data are available for most of the parameters commonly analyzed in wastewaters. Unfortunately, data are unavailable for some parameters critical to leaching analyses, particularly oxidation-reduction potential. Of the analytes for which data are available, alkalinity, chloride, chemical oxygen demand, iron, nitrogen, and sodium are the most highly variable. Magnesium is rarely detected in C&D landfill leachate.

Trace Inorganics

A number of inorganics are found in C&D landfill leachate. Inorganics detected in 50 percent or more of samples are, in order of detection frequency: barium, boron, manganese, aluminum, zinc, copper, lead, chromium, arsenic, cadmium, and mercury.

Organics

Organic species are less frequently analyzed in C&D landfill leachate than other constituents. When organics are sampled, they are less frequently detected than other parameters such as metals. Only phenol, xylene, and acetone were detected in more than 50 percent of the C&D landfill leachate samples. The available acetone data, furthermore, consist only of nine samples.

Table 3-3. Composition of C&D Landfill Leachate

Analyte	N	% Detected	5th %ile	10th %ile	Median	Mean	90th %ile	95th %ile
MAJOR PHYSICAL/CHEMICAL PARAMETERS (mg/L, except pH in Standard Units)								
Alkalinity	94	98.9	54.5	110	1,450	2,202	4,540	5,300
B.O.D.	45	91.1	5.7	9	40	110	170	320
Calcium	35	97.1	44	96.4	205	237	480	578
Chloride	107	100.0	8	13	400	603	1,400	1,630
C.O.D.	90	97.8	24	32	438	1,661	3,730	11,200
Cyanide	30	50.0	0.01	0.011	0.022	0.0665	0.3	0.34
Fluoride	14	92.9	0.05	0.05	0.22	0.63	0.52	5
Iron	54	66.7	4.92	8.6	33.5	89.5	320	680
Magnesium	46	4.4	0.0003	0.0003	0.00465	0.00465	0.009	0.009
Nitrogen	15	100.0	1.59	28.8	156	160	380	400
pH	90	100.0	6.20	6.33	6.90	6.90	7.35	7.70
Sodium	69	100.0	17	20	191	356	953	1,430
Sulfate	65	96.9	21	26	99	289	770	1,000
T.O.C.	30	96.7	6.1	15	180	296.68621	620	1080
TRACE INORGANICS (µg/L)								
Aluminum	18	83.3	100	130	200	676	590	6,350
Arsenic	48	54.2	5	8	32.5	34.9	75	77.3
Barium	27	100.0	100	100	300	638	1,000	1,500
Beryllium	7	14.3	20	20	20	20	20	20
Boron	2	100.0	1,400	1,400	2,650	2,650	3,900	3,900
Cadmium	68	50.0	0.2	2	10	73.1	30	54
Chromium	51	56.9	5	5	18	35.8	100	120
Copper	55	72.7	5.2	7.15	35	75.9	170	465
Lead	68	60.3	2.9	4	40	122	220	360
Manganese	64	100.0	80	620	3450	9,416	17,000	22,000
Mercury	24	50.0	10	20	50	63.8	100	170
Selenium	42	14.3	2	2	3	3.3	5	5
Silver	41	17.1	9	9	10	14.9	30	30
Zinc	41	80.5	10	23	91	575	1,420	2,600
ORGANICS (µg/L)								
1,1-Dichloroethane	23	26.1	0.048	0.048	5.9	7.47	17	17
1,1-Dichloroethene	19	5.3	3,000	3,000	3,000	3,000	3,000	3,000
Acenaphthene	16	18.8	2	2	3	3	4	4
Acetone	9	66.7	31	31	155	992	5,100	5,100
Benzene	23	30.4	0.8	0.8	2.7	3.71	7	7
Chloroethane	23	21.7	5	5	18	82.1	353	353
Ethylbenzene	23	47.8	0.8	1.9	18	26.3	61	79
Methyl Isobutyl Ketone	11	27.3	8.9	8.9	59	106	250	250
Naphthalene	19	21.0	1.4	1.4	5.9	19.0	63	63
Phenol	25	56.0	2.6	11	36.5	323	700	2,990
Trichloroethylene	27	25.9	2	2	6	848	3,000	3,000
Vinyl Chloride	5	40.0	3	3	12.5	12.5	22	22
Xylene	24	58.3	2.3	5.6	69.5	95.2	210	270

Source: Characterization data from the 22 C&D landfills included in the LEACH 2000 database.

3.3.2 Temporal Variability and Indicator Parameters in C&D Landfills

As presented above, the stages of activity in a MSW landfill are well researched. These stages include a leachate generation phase, an acid generation phase, a gas fermentation phase, and a steady-state maturation phase. Corresponding time stages of C&D landfills have not been

postulated. However, several researchers provide time series data for C&D wastes which allow for the opportunity to draw parallels between these different landfills. For MSW landfills, the following factors are indicative of the onset of biological activity:

- Increase in COD and BOD
- Increase in alkalinity
- Drop in sulfate and rise in redox potential
- Drop in pH and increase in volatile acids

Such indications of biological activity have been monitored by Townsend (1998). Findings indicate that some of these effects are evident in C&D waste leachate. Not all of the above indications were present, which may be indicative that different types or degrees of biological activity was taking place. Findings for each parameter are discussed below.

pH

Research has found that the individual components comprising C&D wastes affect pH in different ways. Significant findings include the following:

- The pH from a lysimeter consisting exclusively of concrete was a constant 11 to 12 over time. In contrast, the pH from lysimeters containing only wood, cardboard, or wallboard were relatively constant 4 to 6 over time. This compares to a time dependence of pH in a lysimeter with a more typical mix of C&D waste, where pH was initially 10-11 then dropping to 7 (Townsend, 1998).
- This influence of materials on pH is consistent with previous lysimeter tests in 1980 by other researchers and reported in Townsend (1998); in this 1980 test the pH of a lysimeter containing high masonry C&D mix was 7.45 while the pH of a lysimeter containing high wood mix was 6.9.

These findings suggest that contributions to high pH include concrete, while the presence of organic material in the landfill contributes to lower pH. The temporal dependence of pH was suggested as an indication of biological activity (Townsend, 1998).

Redox and Sulfate

Townsend (1998) conducted lysimeter tests for C&D waste and its individual components. In all cases, redox potential was initially high (100 to 400 mV) and decreased over time to below zero. The lowest values were found for the 'typical' mixture, followed by wallboard, concrete, cardboard, and wood. These results demonstrate that reducing conditions can be present, but can not necessarily determine the source of such conditions in a C&D landfill.

Townsend (1998) reports sulfate levels in lysimeters from typical mixtures of C&D wastes ranged from 600 to 850 mg/L and were shown to result almost exclusively from discarded wallboard. In tests using lysimeters filled with discrete wastes (wallboard, concrete, wood, cardboard), sulfate levels in lysimeters containing only wallboard were elevated and relatively erratic over time, ranging between 800 to 1,200 mg/L. In sharp contrast, sulfate was practically absent from lysimeters containing only cardboard, wood, and concrete. The sulfate

concentrations reported by Townsend (1998) did not significantly decrease during the study period of the lysimeter tests, unlike in MSW. However, Townsend did report the qualitative presence of sulfide odor in the leachate, indicative of the reducing conditions present in biological activity. Therefore, both sulfate and sulfide can be present in C&D landfill leachate simultaneously, due to the large source of mobile sulfate available and the reducing conditions which convert some, but not all, to sulfide in the leachate. These findings were confirmed in the field during ground water monitoring of two C&D landfills in Wisconsin. Sulfate was elevated above background in both cases, while sulfide odor was apparent in one downgradient well (Svavarsson, 1994). These data support the above laboratory findings regarding the mobility of sulfate and its partial conversion to sulfide.

Alkalinity

In an MSW landfill, alkalinity was shown to be time-dependent, increasing during the acid generation phase. Lysimeter tests of C&D wastes provided the following results:

- For a lysimeter containing 'typical' C&D waste, there was an overall rise in alkalinity from 100 to 300 mg/L as CaCO_3 . This was attributed to biological activity as well (due to the formation of bisulfide ion that contributes to alkalinity); the alkalinity of lysimeters containing exclusively high organic components (wallboard, cardboard, wood) increased over time from 20 to 200, while the alkalinity of a lysimeter containing exclusively concrete under unsaturated conditions was a constant 300 mg/L as CaCO_3 over time.
- The absolute values of alkalinity from Townsend (1998) are different than conducted in previous lysimeter tests in 1980 and reported in Townsend (1998); in this 1980 test the alkalinity of a high masonry C&D mix was 70 mg/L as CaCO_3 while the alkalinity of a high wood mix was 350 mg/L CaCO_3 .

These findings suggest that sources of alkalinity in a C&D landfill include organic material, due to decomposition. Concrete is an additional source.

COD and BOD

In an MSW landfill, COD was shown to be time-dependent, increasing during the acid generation phase. Lysimeter tests by Townsend (1998) suggest similar increases for C&D waste. In tests of typical C&D waste, COD concentrations changed over time, showing a peaking behavior indicative of biological activity. Examination of individual materials showed that the presence of cardboard and wood provided the most significant contributions. A lysimeter containing exclusively cardboard gave the most pronounced behavior, with a rise from 50 to 1,600 mg/L before dropping again. Changes of COD for a lysimeter filled with wood were less pronounced, while changes for lysimeters containing only concrete or wallboard were small or negligible. Other experiments of typical C&D wastes in lysimeters by Townsend (1998), however, showed contradictory behavior, showing a drop in COD from 500 mg/L to near zero in unsaturated conditions.

As presented in Ehrig (1983) and discussed in detail in Section 3.2.3 above, the ratio of BOD to COD is an indication of biological activity in MSW landfills. A ratio of 0.6 to 0.8 indicated that

biological activity was present; a ratio less than 0.2 corresponded to the portion of the landfill life cycle of mature, low bio activity. Leachate data from two C&D waste landfills by Waste Management provide analyses for these parameters over a two year period (WMX, 1993). In one landfill (Michigan site), COD ranged from 420 to 4700 mg/L (decreasing over time), with BOD to COD ratio less than 10 percent. At a second landfill (Massachusetts site), COD ranged from 150 to 1,300 mg/L (trend indefinite), with BOD to COD ratios of 40 to 70 percent. These results imply that bioactivity occurred at one of the sites (the Massachusetts site), even though levels of COD are higher at a site with little apparent bioactivity (the Michigan site). These results indicate that COD does not always indicate bioactivity at C&D sites, or additional case studies are needed.

3.4 Industrial Codisposal Landfills

The industrial codisposal landfills in this report are a set of 21 sites included in the data set obtained from Chemical Waste Management (CWM). These landfills are older than the others represented in the CWM data set, with typical opening dates in the 1950's and 1960 and as early as 1927. Although detailed operating histories are not available for these landfills, they all have received a wide variety of wastes throughout their lives, including industrial non-hazardous waste, hazardous waste, and residential and commercial (i.e., municipal waste). It is believed that most of these landfills began operation receiving industrial waste (hazardous, non-hazardous, or both) and at some point began accepting MSW commercially. Most of these landfills currently are closed. It is unknown how those that are currently open are regulated (e.g., it is unknown if they are permitted under Federal Subtitle C hazardous waste regulations or under state Subtitle D non-hazardous waste regulations).

Because of the wide mixture of wastes received and because their operating histories are rather different than most modern MSW, C&D, or commercial hazardous waste landfills, these industrial codisposal landfills are treated as a separate category in this report. A previous study of this group of landfills also confirmed that leachate from these landfills is different from leachate from either purely MSW landfills or purely hazardous waste landfills (Gibbons, et al., 1992).

Because of the rather distinct nature of landfills in this category, no scientific literature is available examining temporal variability or leaching processes in industrial codisposal landfills. This section, therefore, provides only a general overview of the composition of leachate from such landfills. The data presented in Table 3-4, below are from the 21 industrial codisposal landfills represented in the LEACH 2000 database. The constituents included in Table 3-4 represent the parameters most frequently analyzed for in the characterization data included in the database. Constituents are organized into three categories: major physical/chemical parameters, trace inorganics, and organics. The paragraphs below discuss the data for industrial codisposal landfill leachate in each of these categories.

General Parameters

Common physical and chemical parameters are frequently monitored in industrial codisposal landfill leachate. The available data show most of these parameters to be less highly variable in industrial codisposal landfills than in MSW or C&D landfills.

Trace Inorganics

Metals and other inorganics are frequently detected in industrial codisposal landfill leachate. Those analytes detected in 50 percent or more of samples are, in order of detection frequency: aluminum, boron, zinc, manganese, nickel, barium, lead, chromium, copper, arsenic, and cadmium.

Organics

Certain organic species are frequently detected in industrial codisposal landfill leachate. Those species detected in more than 50 percent of samples include: acetone, ethylbenzene, naphthalene, phenol, and xylene.

Table 3-4. Composition of Industrial Codisposal Landfill Leachate

Analyte	N	% Detected	5th %ile	10th %ile	Median	Mean	90th %ile	95th %ile
MAJOR PHYSICAL/CHEMICAL PARAMETERS (mg/L, except pH in Standard Units)								
Alkalinity	267	97.8	700	1,850	6,050	7,271	12,800	19,600
B.O.D.	206	99.0	75	186	1,435	6,042	13,700	23,700
Calcium	52	100.0	29.2	40.5	122	199	310	1,010
Chloride	175	100.0	58.9	135	1,970	3,019	5,900	6,560
C.O.D.	262	98.9	160	473	4,180	9,365	19,800	37,500
Cyanide	153	47.7	0.007	0.014	0.04	0.3031822	0.16	0.325
Fluoride	102	97.1	0.14	0.232	0.68	1.79	4.2	6
Iron	314	100.0	1.81	3.06	19.8	226	820	1,670
Magnesium	41	100.0	39.1	51.1	262	227	382	397
Nitrogen	206	85.0	0.24	0.5	512	730	1,500	1,920
pH	455	100.0	5.63	5.90	7.01	6.84	7.47	7.59
Sodium	53	100.0	9.1	46.5	757	1,093	2,570	3,380
Sulfate	168	89.3	8.44	15.6	95.5	419	1,800	2,090
T.O.C.	520	99.6	14.6	31	1,720	5,724	14,200	23,800
TRACE INORGANICS (µg/L)								
Aluminum	4	100.0	2,140	2,140	73,350	160,960	495,000	495,000
Antimony	150	19.3	4	10	220	535	1,730	1,800
Arsenic	189	73.5	3.5	6	40	212	690	830
Barium	63	93.6	84	140	535	1,877	3,330	8,550
Beryllium	144	9.0	1	1	6	104	387	702
Boron	8	100.0	3,920	3,920	6,470	7,584	18,900	18,900
Cadmium	192	51.6	2	3.7	14	57.4	103	290
Chromium	196	80.1	13	27	226	1,040	900	1,740
Copper	164	75.0	15	21	52	139	260	378
Lead	193	80.3	11	15	139	403	600	1,200
Manganese	162	98.8	60	79.4	1,295	11,059	46,250	52,600
Mercury	188	17.6	0.2	0.2	0.6	1.25	2.2	5
Nickel	166	94.0	50	80	396	7,002	1,450	3,980
Selenium	183	16.9	2	2.6	8	32.4	28	37
Silver	186	19.9	2	9.6	30	45.5	110	150
Thallium	146	19.9	36	46	230	623	1,090	1,650
Zinc	164	99.4	99	160	985	10,946	17,900	47,000
ORGANICS (µg/L)								
1,1-Dichloroethane	210	26.2	15.9	33.5	245	717	1,650	3,360
1,1-Dichloroethene	210	1.9	8.3	8.3	74	272	932	932
Acenaphthene	157	33.1	3.7	5.29	11.25	24.9	71	86.9
Acetone	56	80.4	150	213	5,820	11,648	22,000	58,900
Benzene	210	30.0	5.51	7.1	179	2,127	617	758
Chloroethane	206	4.9	12	13.8	25	56.7	180.5	259
Ethylbenzene	209	65.6	19.4	44	822	1,756	3,360	5,570
Methyl Isobutyl Ketone	15	26.7	11	11	48.7	101	295	295
Naphthalene	159	75.5	6.57	13.2	165	342	832	1,185
Phenol	331	77.0	28	67.3	1,200	606,304	19,000	1,300,000
Trichloroethylene	210	11.0	4.34	4.4	170	802	2,030	3,110
Vinyl Chloride	210	16.7	10.2	102	302	824	2,440	3,000
Xylene	70	70.0	20	22.3	541	1,103	2,020	3,540

Source: Characterization data from the 21 industrial codisposal landfills included in the LEACH 2000 database.

3.5 Hazardous Waste Landfills

The hazardous waste landfills discussed in this section are commercial RCRA Subtitle C landfills that may receive hazardous wastes from multiple industrial sources and sites. While much of the waste received by these landfills is expected to meet the regulatory definition of hazardous waste, the specific form and properties of this waste is likely to be dependent on the generating industry. Therefore, the types and variety of wastes received by these commercial facilities will be dependent on the range and nature of industrial facilities contributing to the landfill. The literature search conducted for this report found no information examining temporal variability or behavior of indicator parameters in hazardous waste landfill leachate. This section, therefore, provides only a general overview of the composition of leachate from such landfills.

The data presented in Table 3-5, below, are from the 17 commercial hazardous waste landfills represented in the LEACH 2000 database. As discussed in Section 3.1 above, these landfills do not necessarily constitute a statistically representative sample of commercial hazardous waste landfills in terms of industries served, types of hazardous waste received, geographic location, or any other criterion. The constituents included in Table 3-5 represent the parameters most frequently analyzed for in the characterization data included in the database. Constituents are organized into three categories: major physical/chemical parameters, trace inorganics, and organics. The paragraphs below discuss the data for hazardous waste landfill leachate in each of these categories.

General Parameters

As for industrial codisposal landfills, the available data show most of the common physical and chemical parameters to be less highly variable in hazardous waste landfill leachate than in leachate from MSW or C&D landfills.

Trace Inorganics

Metals and other inorganics are frequently detected in hazardous waste landfill leachate. Those analytes detected in 50 percent or more of samples are, in order of detection frequency: boron, zinc, arsenic, barium, nickel, manganese, chromium, copper, aluminum, cadmium, selenium, and lead. Certain of these metals, including some that are among the most frequently detected (e.g., arsenic, barium, and chromium), are part of the toxicity characteristic for hazardous waste.

Organics

Organic species are frequently monitored in hazardous waste landfill leachate, more frequently, in fact, than many other analytes. Those species detected in more than 50 percent of samples include: 1,1-dichloroethane, acetone, methyl isobutyl ketone, naphthalene, phenol, and trichloroethylene.

Table 3-5. Composition of Hazardous Waste Landfill Leachate

Analyte	N	% Detected	5th %ile	10th %ile	Median	Mean	90th %ile	95th %ile
MAJOR PHYSICAL/CHEMICAL PARAMETERS (mg/L, except pH in Standard Units)								
Alkalinity	138	100.0	538	777	2,385	2,838	5,600	6,750
B.O.D.	306	98.0	68	174	1,770	2,639	5,144	6,820
Calcium	98	100.0	18.9	28	351	616	1,600	3,400
Chloride	342	100.0	96	180	1,390	7,212	25,900	31,100
C.O.D.	433	100.0	379	650	3,010	4,279	9,130	11,000
Cyanide	321	66.0	0.06	0.09	8.35	14.1	18	47.4
Fluoride	202	99.0	0.2	0.3	2.1	20.4	26.15	62.9
Iron	449	97.8	0.76	1.2	15.3	250	450	1,050
Magnesium	95	96.8	8.35	14.8	150	186	358	575
Nitrogen	304	62.8	0.11	0.405	43.3	168	271	357
pH	2,017	100.0	3.17	4.63	7.37	7.46	9.7	11.8
Sodium	273	99.3	90	238	4,040	6,563	18,800	22,100
Sulfate	275	94.6	12.9	22.6	725	3,656	9,275	11,750
T.O.C.	833	99.9	43.3	150	3,310	3,945	8,870	10,600
TRACE INORGANICS (µg/L)								
Aluminum	50	66.0	90	120	921	22,299	12,000	52,000
Antimony	172	24.4	12	20	155	457	1,500	1,800
Arsenic	463	90.7	9	19.8	1,500	42,806	131,000	173,000
Barium	319	89.7	53	71	150	345	820	1,200
Beryllium	172	14.5	1	1.1	3	6.06	20	25
Boron	68	95.6	340	510	3,660	20,774	70,000	98,000
Cadmium	477	57.4	1.2	4.3	52.5	12,332	1,800	19,000
Chromium	443	69.8	15	24	140	1,286	1,830	5,600
Copper	320	67.8	16	27	170	1,079	2,200	6,100
Lead	423	50.8	7	9	100	807	590	1,400
Manganese	321	88.5	29	60	1,300	19,304	55,700	110,000
Mercury	444	36.3	0.22	0.3	3	54.8	50	110
Nickel	314	88.9	55.2	76	1,200	3,363	7,900	14,800
Selenium	467	56.3	8	12	110	256	300	900
Silver	392	23.7	2.7	6.8	10	19.3	38	58
Thallium	138	9.4	6.7	10	56	92	190	260
Zinc	355	92.4	30	54	458	7,640	11,100	38,000
ORGANICS (µg/L)								
1,1-Dichloroethane	953	52.6	13	28.7	950	31,403	13,700	32,000
1,1-Dichloroethene	952	24.8	6.72	28.7	990	22,428	5,630	60,900
Acenaphthene	220	5.9	4.55	23	84	191,220	2,390	2,480,000
Acetone	82	85.4	110	181	5350	24,221	54,800	84,100
Benzene	952	27.9	5.22	8.84	81.6	3,949	1,970	5,500
Chloroethane	948	8.8	6.51	45	602	11,188	5,070	7,370
Ethylbenzene	946	39.2	12.8	19.5	170	135,832	20,200	728,000
Methyl Isobutyl Ketone	49	61.2	46	64	938	26,108	53,500	300,000
Naphthalene	235	59.6	3.82	4.8	39	85,647	918	2,375
Phenol	551	90.9	75.9	197	21,000	9,189,721	272,000	1,550,000
Trichloroethylene	955	59.7	16.6	33.75	1,775	91,896	48,050	220,000
Vinyl Chloride	952	36.1	23.3	96.6	1,755	9,697	22,400	34,700
Xylene	103	41.8	13	14	81	915	2,770	4,800

Source: Characterization data from the 17 commercial hazardous waste landfills included in the LEACH 2000 database.

3.6 Comparison of Leachate Composition

This section presents a comparison of leachate characteristics for the four types of landfills discussed in the previous sections. Section 3.6.1 provides an overview of major factors that theoretically influence the composition of leachate. Section 3.6.2 qualitatively compares the four types of landfills in terms of these factors. Section 3.6.3 presents a detailed quantitative comparison of the four types of landfills with regard to the major indicator parameters that affect contaminant mobility (i.e., those factors introduced and discussed in Section 3.2.3, such as pH). Sections 3.6.4, 3.6.5, and 3.6.6 examine the comparative statistics by landfill type for other major physical and chemical parameters, trace inorganics, and organics, respectively.

3.6.1 Overview of Factors Affecting Leaching Medium Composition

The composition of the leaching medium is determined in large part by the chemical properties (elemental and chemical composition) and physical properties (e.g., particle size, porosity) of the waste. The leaching medium refers to the liquid contacting the waste. For example, in the TCLP analysis the leaching medium is an aqueous solution of organic and mineral acid, intended to simulate those acids present in an MSW landfill. In turn, the leaching medium affects the mobility of the contaminants in the wastes.

In general, there are three factors influencing the composition of leachate: (1) composition of infiltrating liquid; (2) composition of waste disposed; and (3) the site-specific operations of the waste management unit. As shown below, there is much variability in these three areas both within a single landfill and from one landfill to another; this variability contributes to variability in the resulting leachate.

Infiltrating Liquid

Moisture can be present in a landfill both from the waste itself (e.g., wet refuse) and from precipitation or other sources of water percolating or entering the landfill cell. These latter sources of water result from precipitation, run-on, and ground water. Each of these sources can result in differences in the composition of this infiltrating water.

Precipitation often has acidic properties and can be sources of both acidity and anionic compounds to the landfill. Acidic components in rainwater include carbonic acid (from natural dissolution of carbon dioxide), sulfuric acid (from typically man-made sources of sulfur dioxide), and nitric acid (from oxides of nitrogen) (Wark, 1981).

The composition of runoff is affected by the composition of the precipitation and further affected by organic matter in the surrounding vegetation. Finally, ground water may enter a waste management unit if the unit is constructed below the water table or in cases where the water table has seasonal or yearly fluctuations. The most extreme example of ground water affecting the leaching medium is in cases of acid mine drainage, where sulfuric acid from sulfides in the ore body result in increased mobility of metals.

The quantity of the infiltrating liquid has an important effect on leachate quantity and leachate quality. The quantity of infiltrating liquid is affected by the climatic conditions of the site and

the presence of controls to limit these affects. For example, a slurry wall or an engineered liner will serve to keep ground water away from the landfill, and a cap (at closure) will reduce the quantity of precipitation entering the landfill. Similarly, the design of the surrounding area with regard to slopes and vegetation will affect the contribution of runoff to the moisture loading of the landfill.

Waste Composition

The composition of the waste itself affects the composition of the leachate in several ways. First, the refuse may have some moisture or readily mobile constituents which immediately affect leachate composition. Conversely, the waste may not have residual moisture and be able to adsorb surrounding moisture and associated aqueous contaminants. Variations in the wastes disposed within a landfill or between different landfills result in differences in the mobility of these constituents.

Second, biological processes within a landfill may transform some of the constituents within the waste into readily mobile species. The type and density of bacterial populations and propensity of the waste to degrade will affect the biological processes. These biological processes are not constant, but can go through cycles of low and high activity as discussed in the sections on MSW and C&D landfills. This results in temporal variation in leachate.

Finally, the physical properties of the waste (e.g., porosity, particle size) affect mass transfer phenomena between the waste and leachate and affect the magnitude of the value of the properties in the leachate. Leachate may flow through the waste as channels due to the large size of waste materials, and the moisture (degree of saturation) will vary throughout the landfill (Ehrig, 1983). The waste itself may exhibit adsorptive or ion-exchange properties, influencing leachate composition in ways that may not be able to be correlated with other parameters.

Landfill Operations

Landfill operations can affect the other two factors identified above. For example, the waste entering a landfill is influenced by waste screening and approval procedures. The type of liquid entering a landfill is influenced by several of the design criteria specified above such as runoff controls and water table interactions, but also by leachate collection and recycling techniques practiced by the individual landfill. Other properties are affected by the location of the landfill: its climatic location influences the quantity and frequency of precipitation as well as the ambient temperature which is an important factor in any biological processes present in the landfill.

Leachate properties are also affected by specific waste management practices. Other important operating properties include the degree to which biological degradation is encouraged through practices such as waste spreading and the type of daily cover employed. The type of equipment used in compacting affects infiltration; the compaction of the waste affects its mass transfer properties, subsequently affecting how liquid moves through and around the landfilled materials. In MSW landfills in particular, compaction also can result in an overall anaerobic environment in the landfill. Low compaction will allow increased oxygen within the landfill, and subsequently influence the type and duration of biological activity (Ehrig, 1983).

Data from Ehrig (1983) demonstrate how landfill operating practices influence leachate composition. An MSW landfill operating by spreading waste as a thin layer had very different COD and BOD leachate characteristics than a landfill operating with thick (2 m) layers, or a landfill operating with thick layers together with leachate recirculation. The thin layers resulted in the lowest levels of BOD and COD in the leachate throughout the life of the landfill, indicating higher methane gas production. Leachate recirculation also decreased BOD and COD levels in the leachate.

3.6.2 Comparison of Factors Affecting Leaching Medium Composition

There can be significant differences in all three of the factors discussed above among landfill types. These differences are discussed below.

Composition of Infiltrating Liquid

In most cases, the composition of the liquid infiltrating will be similar for most types of landfills (i.e., the liquid will resemble rainwater). Differences in infiltrating liquid are more likely to be linked to climate and location than to landfill type. Potential differences among landfill types, however, occur with water resulting from the waste itself, as well as the quantity of liquid infiltrating through the unit. These factors are discussed under waste composition and landfill operations.

Waste Composition

The most obvious differences among the types of landfills discussed here is in the wastes disposed. These differences affect not only the type of toxic constituents available to leach, but also the leaching solution generated within the landfill. These factors include the following:

- The waste may have some moisture and generate leachate immediately, or conversely may not have residual moisture and be able to adsorb surrounding moisture and associated aqueous contaminants. C&D wastes are expected to contain little moisture and therefore are not expected to immediately generate leachate (Townsend, 1998). In contrast, MSW is expected to be wetter with moisture contents of 25 percent (Ehrig, 1983). The moisture content of wastes in industrial codisposal landfills and commercial hazardous waste landfills would be highly dependent on the mixture of industries utilizing the specific landfill.
- Biological processes within the landfill may transform some of the constituents within the waste into readily mobile species and generate time dependent profiles of indicator parameters. As discussed above for MSW landfills, the combination of waste composition and landfill conditions results in biological activity which affects levels of indicator parameters. The levels of organic matter in MSW range from 50 to 70 percent; in contrast, biodegradable levels of organics in C&D landfills are expected to be lower (Thompson, 1998). The degradable fraction of waste in industrial codisposal landfills and commercial hazardous waste landfills is likely to be lower than that in MSW. Certain industries, however, may generate highly biodegradable organic wastes. The presence of such wastes in large

quantities may increase the likelihood of organic processes occurring in these types of landfills. The presence of toxic constituents (particularly metals) in hazardous waste landfills, however, may inhibit certain biological processes.

- Wastes may release different contaminants in the short and long term, including both toxic and indicator parameters. Such differences in waste composition result in differences in the gross parameters of leachate. For example, C&D wastes include: gypsum (sources of calcium and sulfate), wood wastes (similar in composition to fractions of MSW), and concrete and similar materials (sources of dissolved minerals). Hazardous waste landfills will contain larger quantities of toxic constituents, creating the potential for long-term release of these constituents.
- The physical properties of the waste (e.g., porosity, particle size) affect mass transfer phenomena between the waste and leachate. C&D waste, for example, is expected to be larger or bulkier than other types of waste with potentially less surface area available for leaching and perhaps a greater opportunity for channelized flow.

Landfill Operations

There are expected to be differences in the operation of different landfill types. For example, localities generally require compaction of the waste and daily cover (e.g., six inches of soil) for an MSW landfill. In comparison, a variety of design and operating requirements concerning C&D landfills were reviewed by ICF (1995), including ground water monitoring and location standards. These data are from the early 1990s so that requirements may have changed since that time. Nineteen states require offsite (commercial) facilities to provide six inches of daily cover (i.e., consistent with MSW requirements). An additional 26 states require cover at a less frequent interval (i.e., less stringent than MSW requirements). Therefore, 45 states require some type of cover for C&D landfills during operation, with most requiring intermittent cover. Detailed data on state requirements for industrial Subtitle D landfills is not available, but the available information suggests that these requirements are highly variable depending on the state. Hazardous waste landfill operations are likely to be the most consistent because these landfills are stringently regulated under federal requirements, which include cover, monitoring, and run-on and run-off controls.

The differences in cover application are significant because cover impacts oxygen conditions in a landfill, and even the method of applying cover influences biological processes in a landfill (as discussed above in Section 3.6.1 for MSW landfills). High acid production and gas generation in an MSW landfill relies on low oxygen conditions (Pohland, 1986). Cover, along with run-on controls, control the quantity of infiltrating liquid and may affect infiltrating liquid characteristics.

3.6.3 Comparison of Factors Affecting Contaminant Mobility

Sections 3.2.3 and 3.3.2 discussed several factors or indicator parameters that are significant for contaminant mobility. This section uses data from the LEACH 2000 database to compare the following of these significant parameters among landfill types:

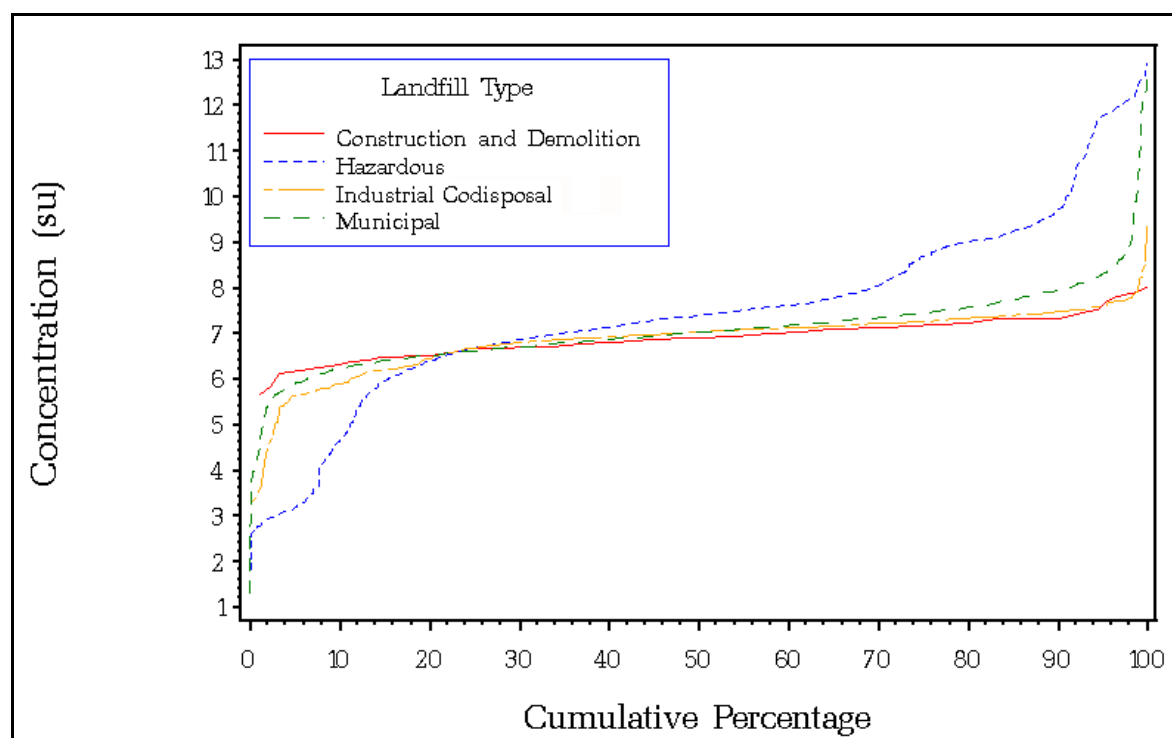
- pH
- Redox potential and sulfate
- Alkalinity
- TOC, BOD, and COD

pH

Figure 3-7 presents a graphical comparison of pH among landfill types. C&D landfills show the narrowest range of pH, while hazardous waste landfills show the greatest variation. The majority of MSW leachate observations show a relatively consistent pH, but with significant instances of both high and low values. Industrial codisposal landfills also show a relatively consistent pH, but with more instances of low pH than MSW landfills and far fewer instances of high pH. As discussed in previous sections, the narrower range of pH in the C&D scenario is indicative of a more constant leaching scenario over time, unlike more dynamic conditions in a MSW landfill where high concentrations of organic acids are followed by a general increase in pH. These pH data are consistent with a comparison of C&D landfill leachate with MSW landfill leachate from at least one other source. Specifically, data for 25 C&D landfills (from Waste Management) showed a pH range of between 6.1 and 8, compared to data for 152 MSW landfills showed a pH range of much wider range (from 4 to >12) with a median only slightly higher (about 6.9 for C&D versus 7.1 for MSW).

The available literature provides little insight into the pH profiles seen here for hazardous waste and industrial codisposal landfills. The wide variation seen for hazardous waste landfills, however, may be due to variations in waste composition. Hazardous waste landfills may receive highly alkaline or highly acidic wastes.

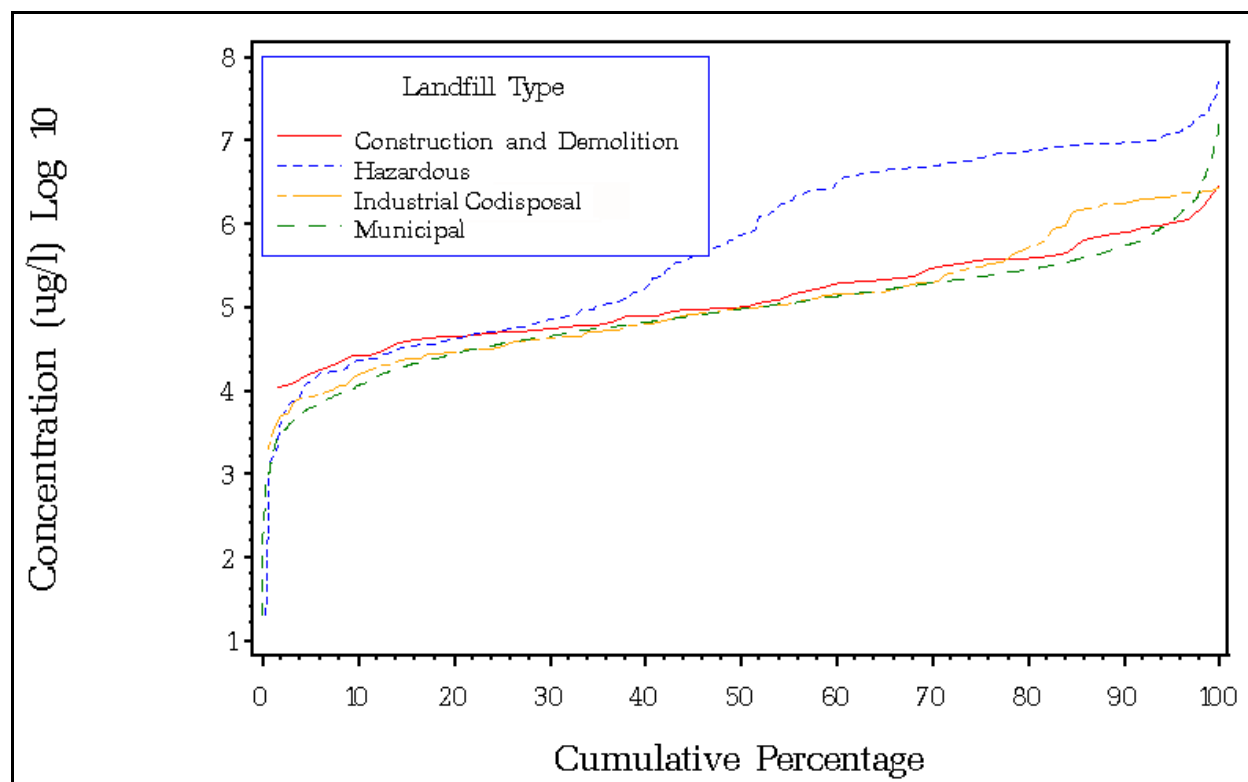
Figure 3-7. Cumulative Distribution of pH by Landfill Type



Redox Potential and Sulfate

Unfortunately, only limited data (approximately 10 total observations) are available for oxidation-reduction potential in the LEACH 2000 database. As discussed previously, sulfate may be a surrogate indicator for oxidation-reduction potential, because sulfates convert to sulfides under reducing conditions. Figure 3-8 compares sulfate concentrations among the landfill types. MSW leachate and hazardous waste leachate shows the highest maximum sulfate concentrations and also the greatest variability. For MSW landfills this variability is consistent with the observation in section 3.2.3 that sulfate concentrations typically decrease over time in MSW landfill leachate, reflecting changes in pH and redox potential. Data are not available to indicate whether the sulfate profile for hazardous waste landfills is related to changes over time or other factors. In the case of C&D landfill leachate, sulfate levels never drop below approximately 10 mg/L. This is consistent with the conclusion in Townsend (1998) that sulfate levels were higher in C&D waste lysimeter leachate than in MSW landfill leachate.

Figure 3-8. Cumulative Distribution of Sulfate by Landfill Type



TOC, COD, and BOD

Figures 3-9 through 3-11 compare the four landfill types in terms of several indicators of organic content and biological activity: total organic carbon (TOC), chemical oxygen demand (COD), and biochemical oxygen demand (BOD). Figure 3-9 shows that TOC is highest in hazardous waste and industrial codisposal landfills. TOC levels in MSW and C&D landfills are similar in the low end, but a larger percentage of MSW landfills may have high TOC.

As shown in Figure 3-10, while hazardous waste and industrial codisposal landfills generally have higher levels of COD, MSW landfills display the greatest variability in COD. As discussed in section 3.2.3, COD has been shown to be correlated with volatile fatty acid (VFA) concentration in MSW landfills. Therefore, the variability in COD (and, by inference, VFA) is consistent with an early, acid-generating stage (i.e., high COD and VFA) followed by less active stages (i.e., low COD and VFA). Hazardous waste and industrial codisposal landfills have a more constant distribution of COD, suggestive of less variability in behavior. C&D landfills generally show lower levels of COD than other types of landfills.

Figure 3-11 shows that BOD levels in C&D landfills are generally much lower than those in other landfills. This result is consistent with lower COD levels and with the expectation of lower biological activity in these landfills. Figure 3-12, which shows BOD/COD ratios, sheds additional insight into biological activity for each landfill type. As discussed in Section 3.2.3, BOD/COD ratios closer to 1 indicate that biological degradation is favorable. At the median, BOD/COD ratios are lower in C&D landfills than in other types of landfills. In fact, BOD/COD ratios are lower in all but a small percentage (20 percent) of C&D landfills. Interestingly,

BOD/COD ratios in relatively inactive (BOD/COD less than 0.5) MSW landfills are much lower than ratios in similarly inactive hazardous waste landfills. In more active landfills (about 35 percent of landfills of both types), ratios are somewhat higher in MSW landfills than hazardous waste landfills.

Figure 3-9. Cumulative Distribution of Total Organic Carbon (TOC) by Landfill Type

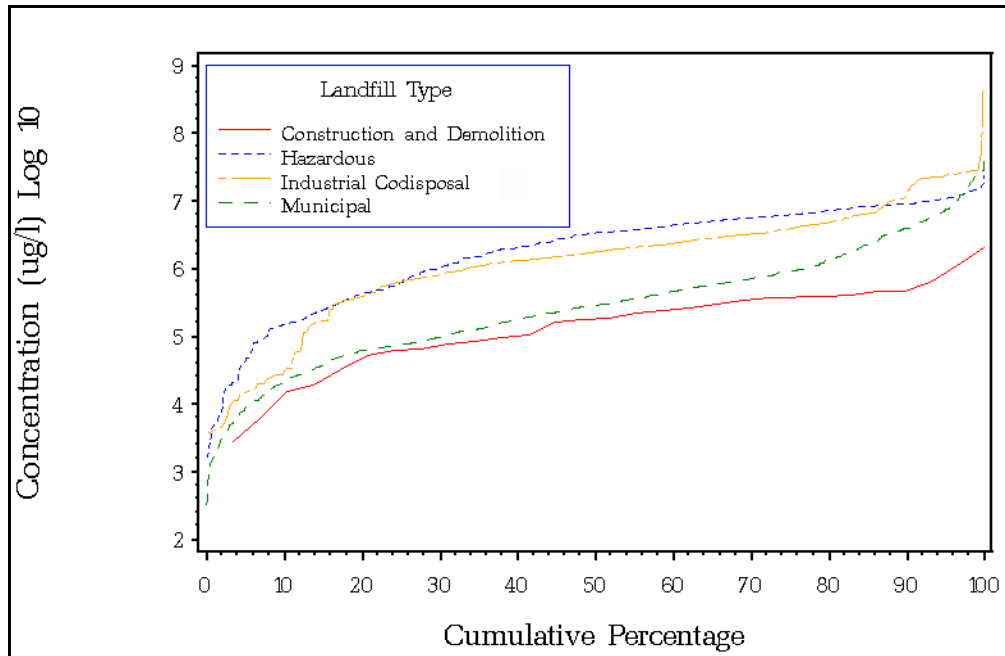


Figure 3-10. Cumulative Distribution of Chemical Oxygen Demand (COD) by Landfill Type

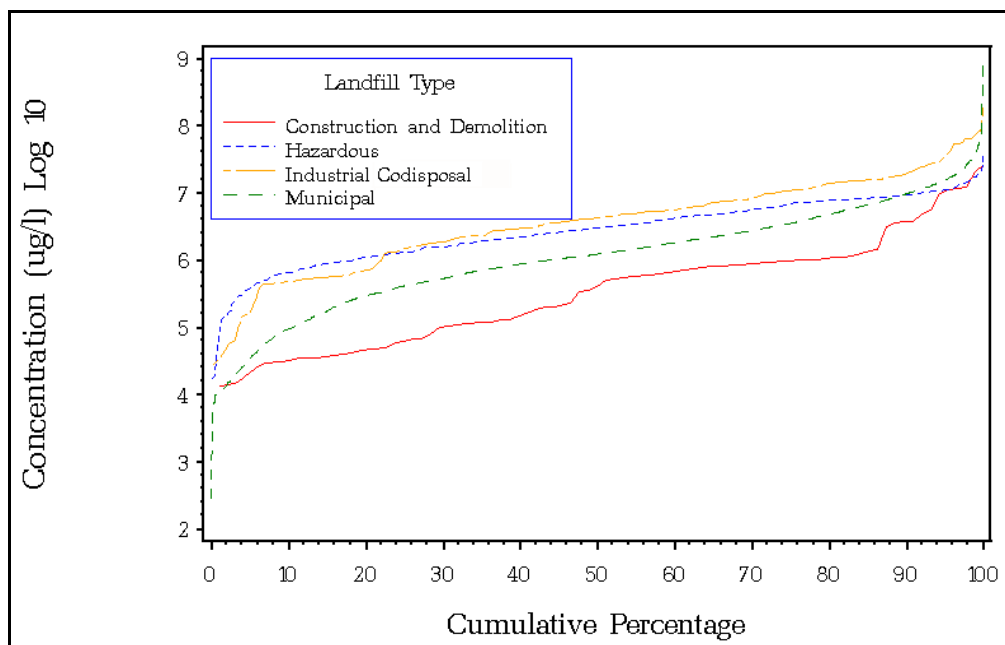


Figure 3-11. Cumulative Distribution of Biochemical Oxygen Demand (BOD) by Landfill Type

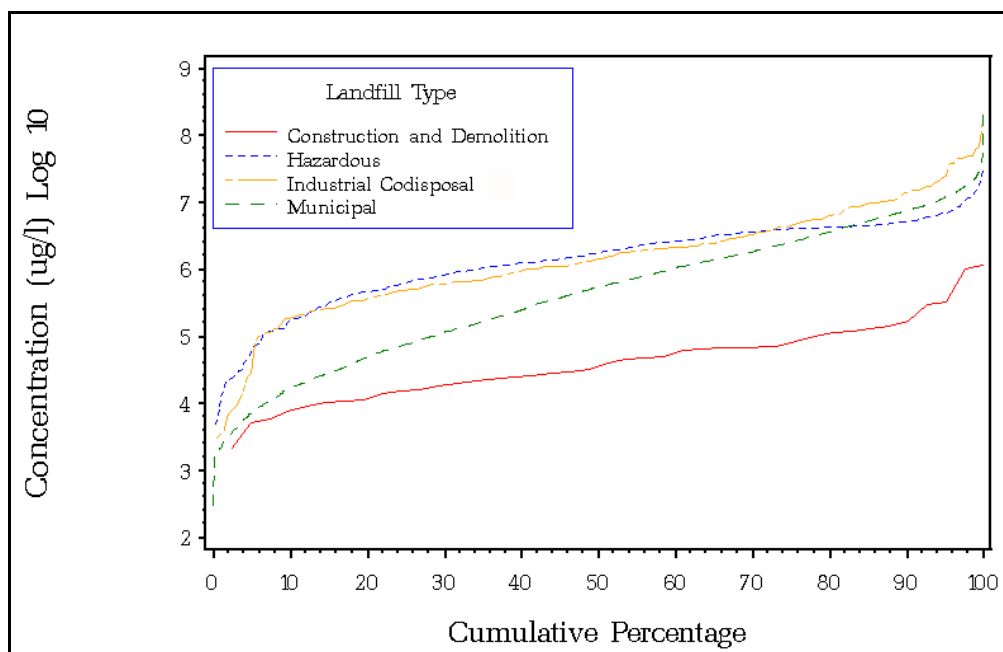
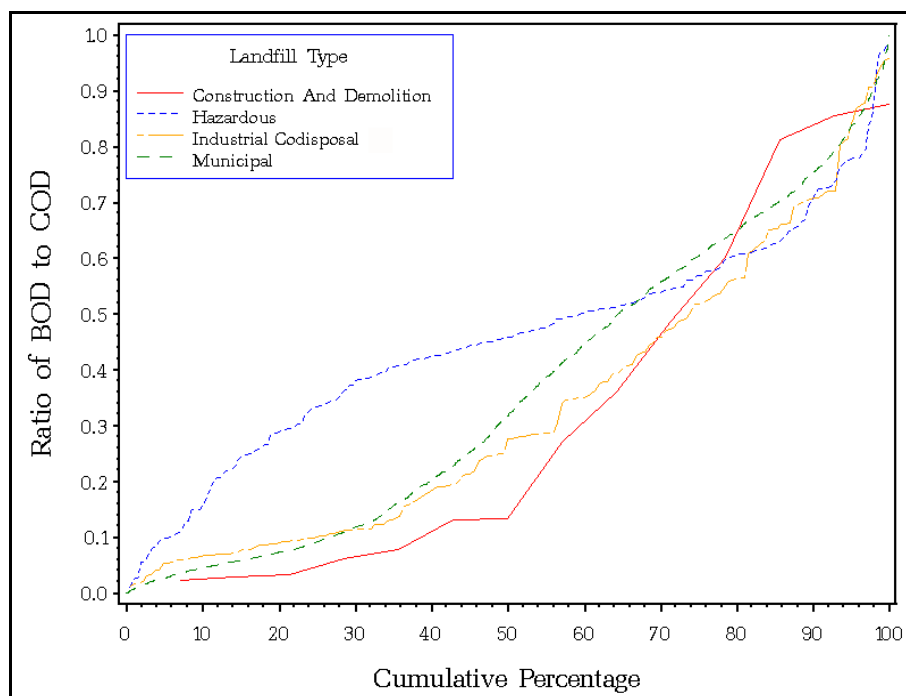


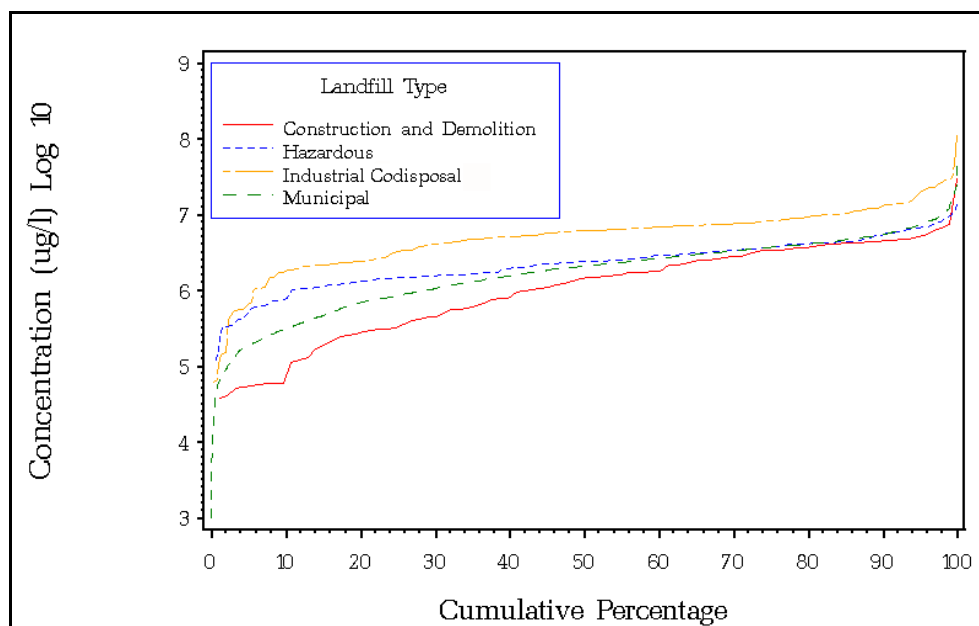
Figure 3-12. Cumulative Distribution of BOD/COD Ratio by Landfill Type



Alkalinity

Figure 3-13 compares alkalinity in each of the four landfill types. The distributions shown are similar in shape to those for COD, with MSW landfills showing the greatest variability. This may indicate that organic decomposition plays a role in alkalinity, at least in MSW landfills.

Figure 3-13. Cumulative Distribution of Alkalinity by Landfill Type



3.6.4 Comparison of Other Major Physical and Chemical Parameters

This section presents data on the other major parameters that were not covered in the previous section. Many of the remaining parameters for which extensive data are available are the major anions. As shown in Figure 3-14, the following of the remaining parameters show roughly similar distributions:

- calcium
- chloride
- fluoride
- sodium

Each of these constituents is found in generally higher concentrations in hazardous waste landfills. They are found in generally lower (with the exception of calcium) and non-varying concentrations in C&D landfills. MSW landfills are generally between these two extremes, but show the greatest variation, although this may be due to the much larger sample size for MSW landfills.

Figure 3-15 shows parameters that do not fit this pattern. As shown in Figure 3-15, cyanide concentrations are substantially higher in hazardous waste landfills than in all other types of landfills. Iron concentrations are roughly similar across the landfill types, although highest at the median in C&D landfills. Nitrogen is lowest in hazardous waste landfills. Magnesium is rarely detected in C&D landfills and, when detected, is found only at very low levels.

Figure 3-14. Cumulative Distribution of Parameters Found in Higher Concentrations in Hazardous Waste Landfills

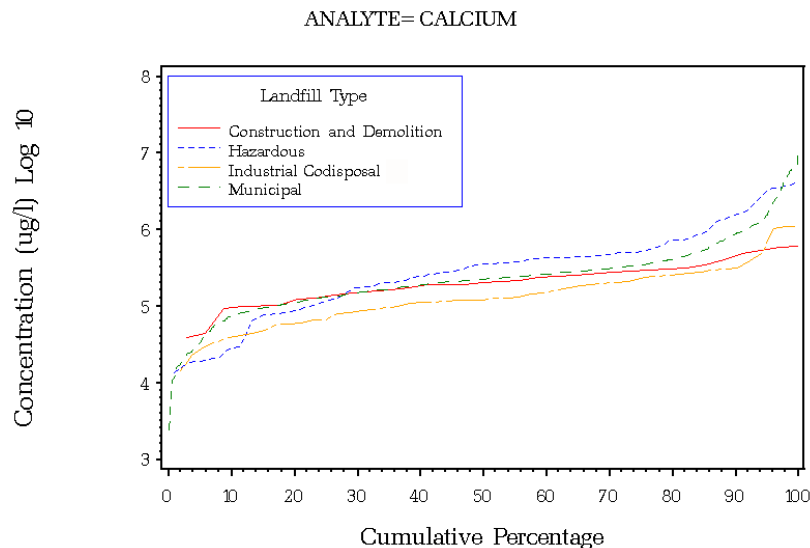
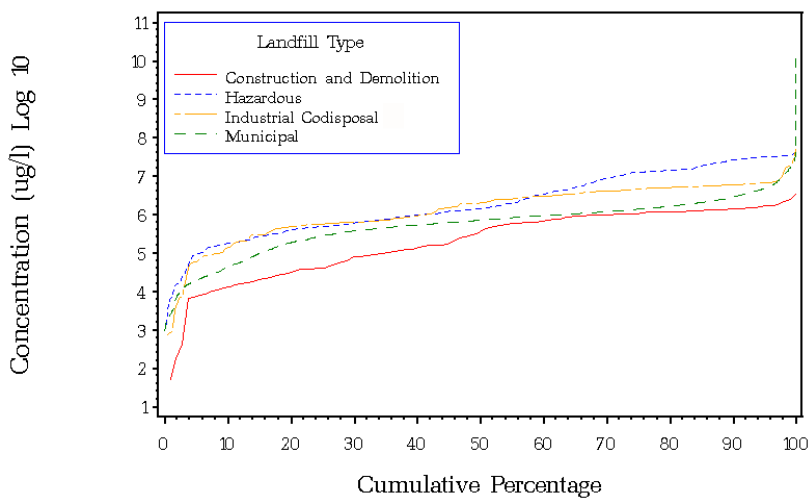
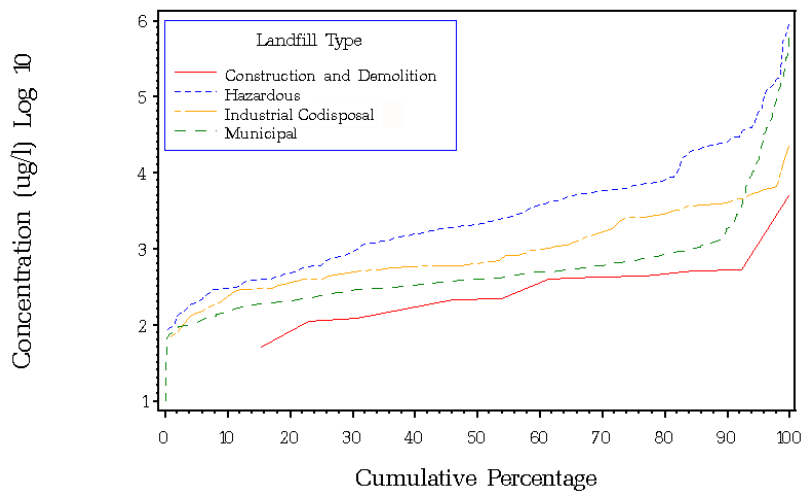


Figure 3-14. Cumulative Distribution of Parameters Found in Higher Concentrations in Hazardous Waste Landfills (continued)

ANALYTE= CHLORIDE



ANALYTE= FLUORIDE



ANALYTE= SODIUM

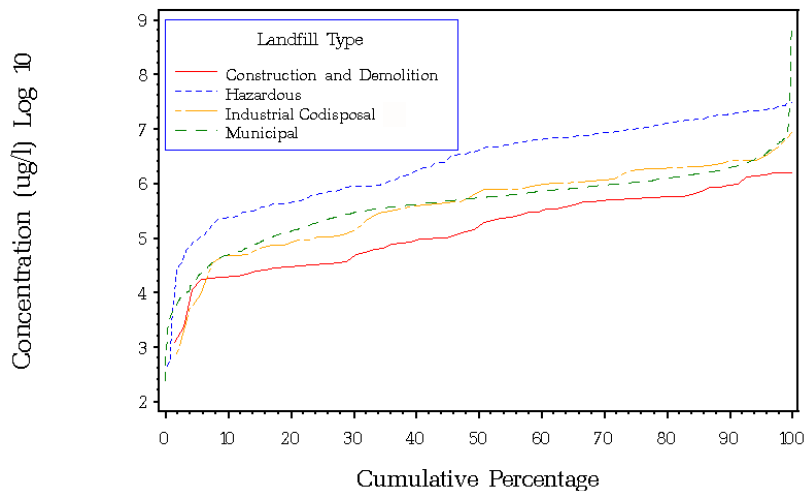


Figure 3-15. Cumulative Distribution of Other Parameters

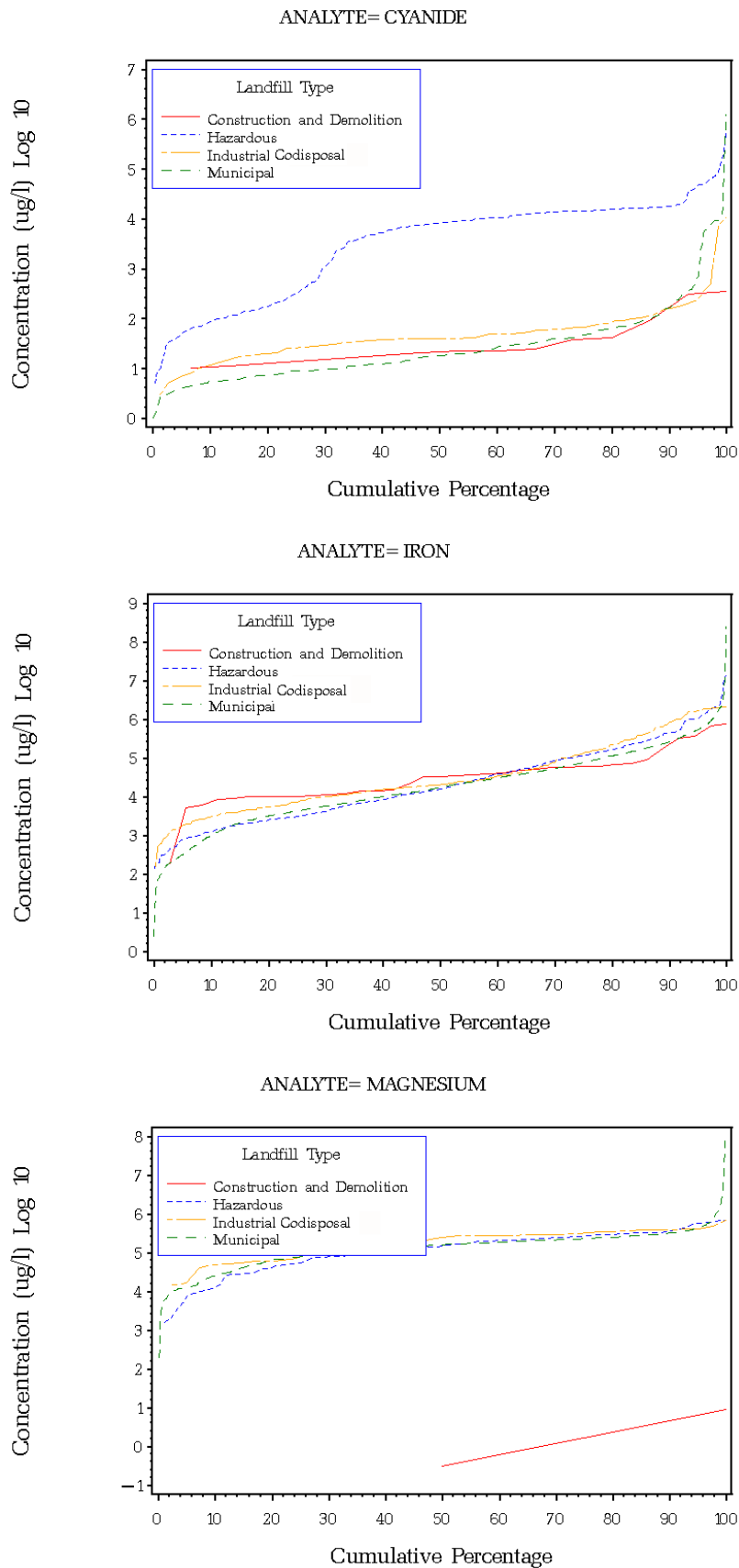
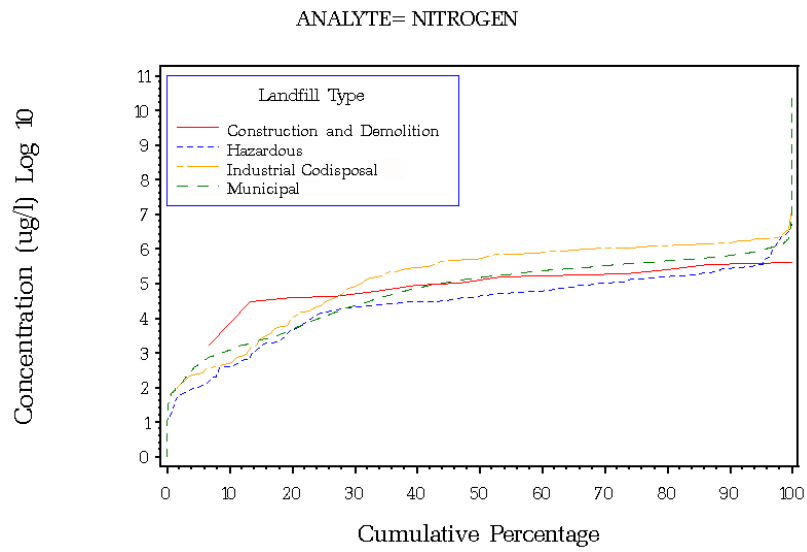


Figure 3-15. Cumulative Distribution of Other Parameters (continued)



3.6.5 Comparison of Trace Inorganics

This section compares concentrations among the landfill types for those trace inorganics (e.g., metals) for which a large number of observations are available. As shown in Figure 3-16, the following constituents are found in generally higher concentrations in hazardous waste landfills than in other types of landfills:

- arsenic
- cadmium
- copper
- nickel
- selenium

As shown in Figure 3-17, the following constituents are found in higher concentrations in both hazardous waste and industrial codisposal landfills:

- chromium
- lead
- zinc

Figure 3-18 shows cumulative distributions for other trace inorganics. Observations for these remaining constituents are as follows:

- Aluminum is found in higher concentrations in hazardous waste and MSW landfills than in C&D landfills (the data for aluminum for industrial codisposal landfills are insufficient to draw any conclusions).
- Barium is found in higher concentrations in MSW and industrial codisposal landfills.
- Boron is found in high concentrations in a percentage (about 20 percent) of hazardous waste landfills, but at the highest maximum concentrations in a MSW landfills (the data for boron for C&D and industrial codisposal landfills are insufficient to draw any conclusions).
- Manganese exceeds 1,000 µg/L for the majority of C&D landfills, but the highest maximum concentrations are found in hazardous waste landfills.
- Mercury is infrequently detected (less than 20 percent of the time) in MSW and industrial codisposal landfills. When detected, mercury is found in higher concentrations in hazardous waste and C&D landfills than in other types of landfills.
- Antimony, beryllium, silver, and thallium are infrequently detected in landfills of any type. Therefore, graphs for these constituents are not presented here.

Figure 3-16. Trace Inorganics Found in the Highest Concentrations in Hazardous Waste Landfills

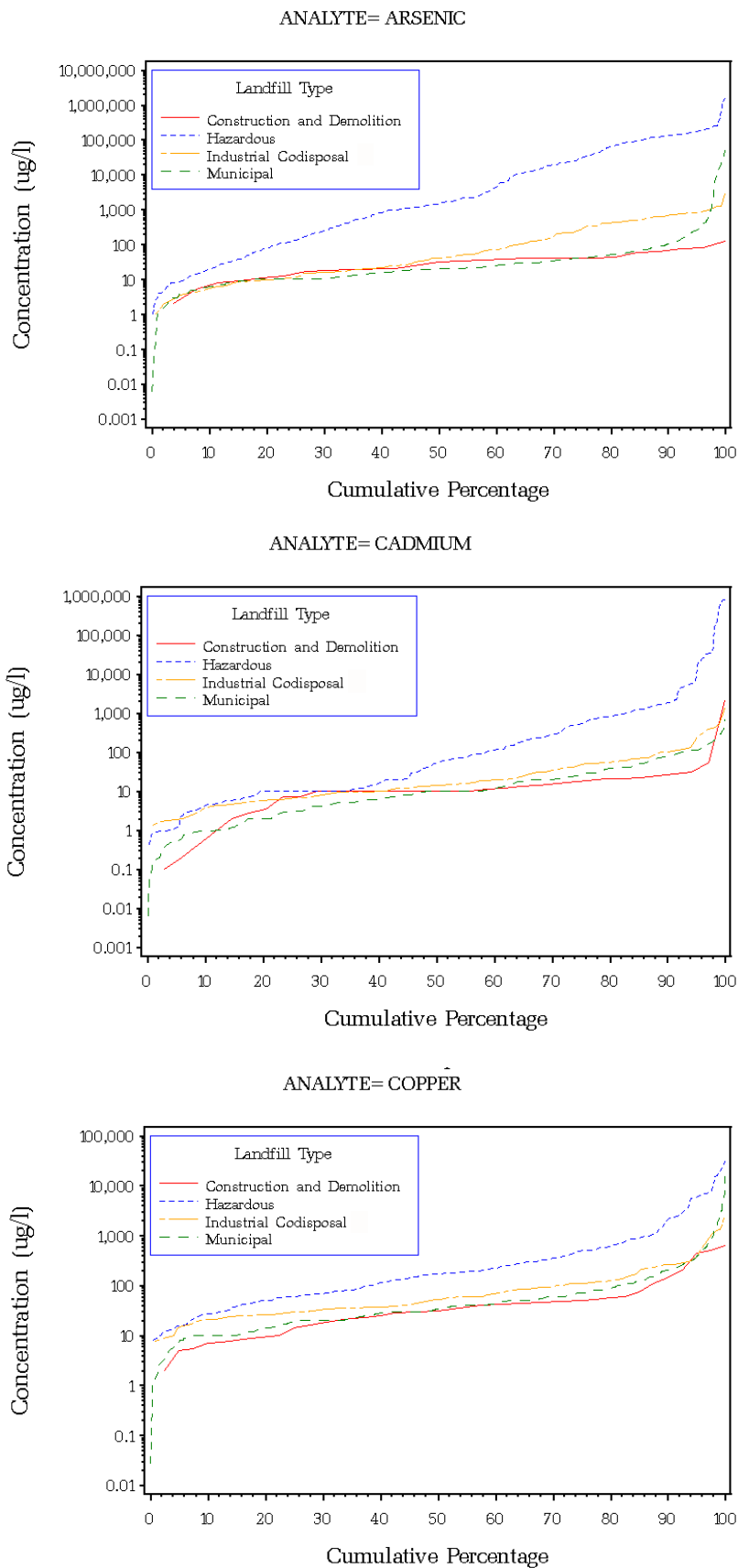


Figure 3-16. Trace Inorganics Found in the Highest Concentrations in Hazardous Waste Landfills (continued)

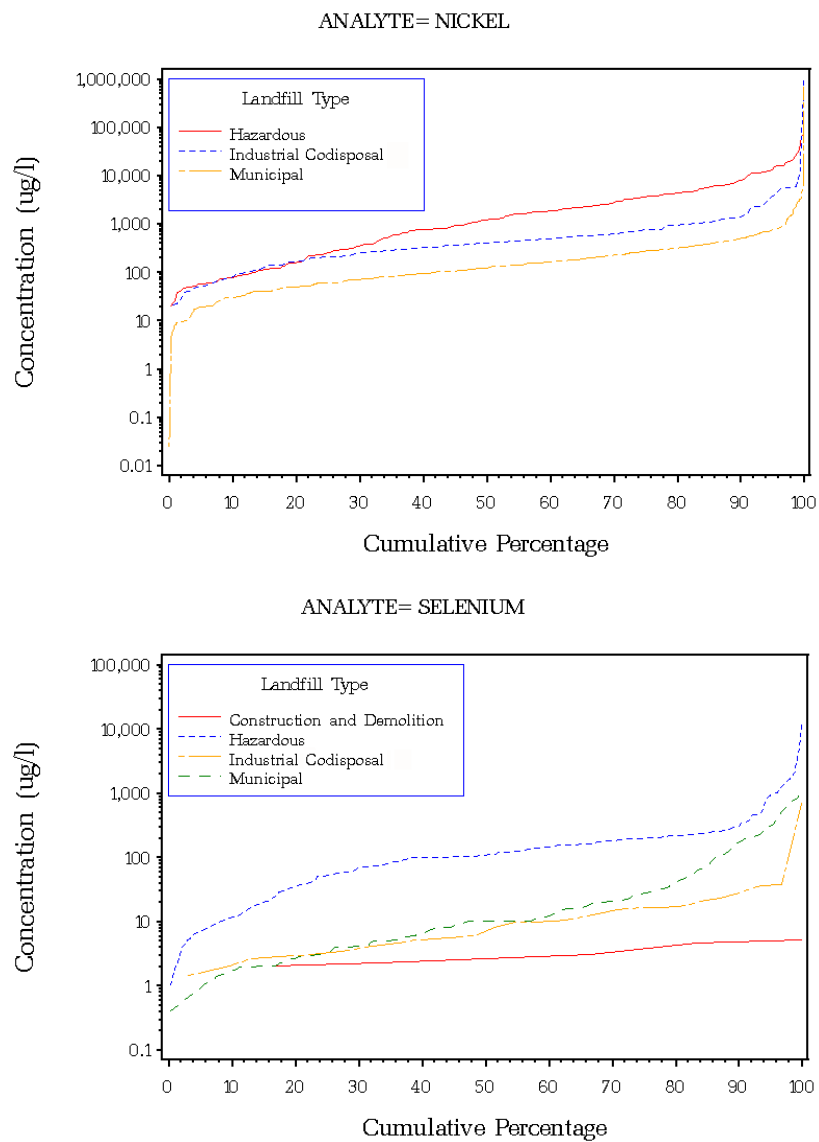
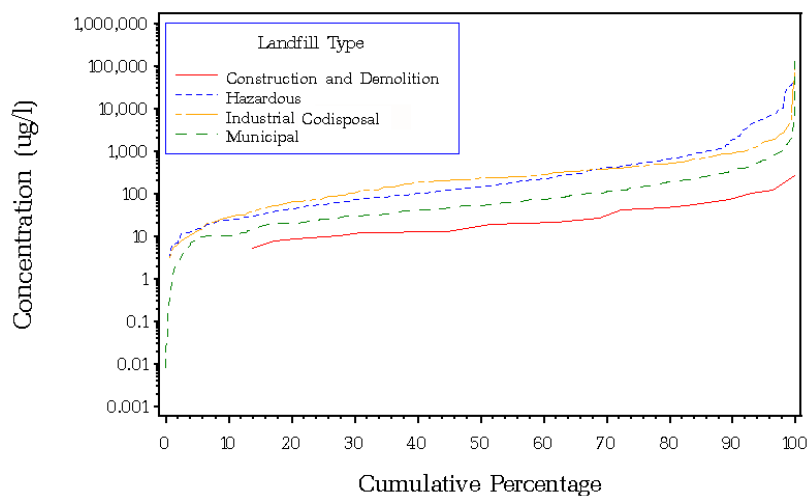
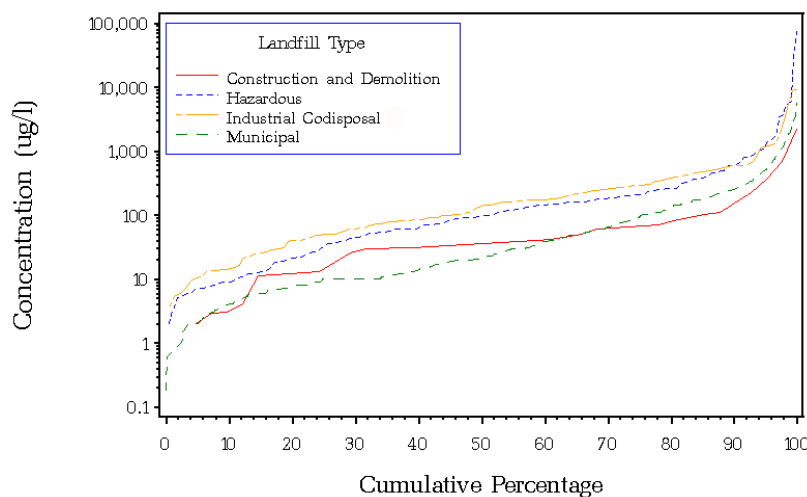


Figure 3-17. Trace Inorganics Found in the Highest Concentrations in Both Hazardous Waste and Industrial Codisposal Landfills

ANALYTE= CHROMIUM



ANALYTE= LEAD



ANALYTE= ZINC

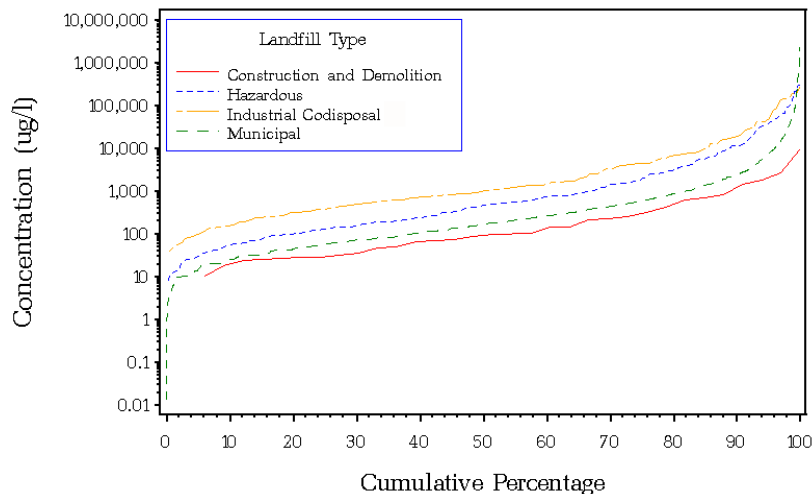
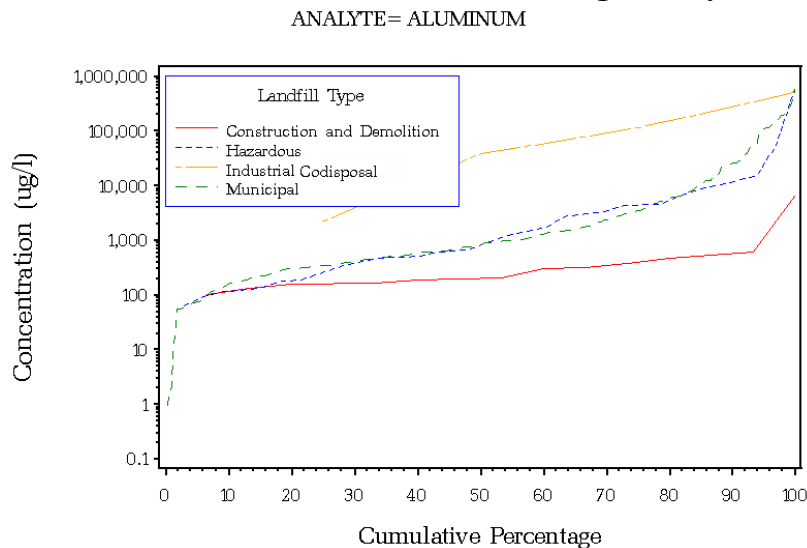
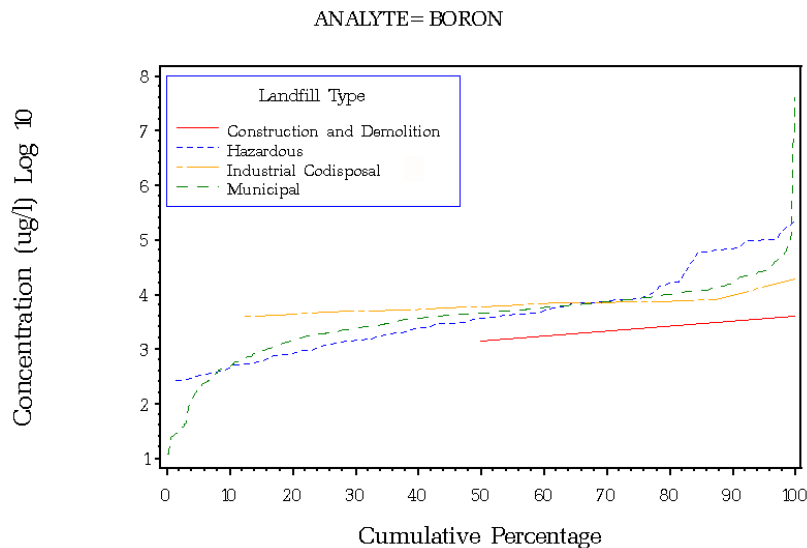
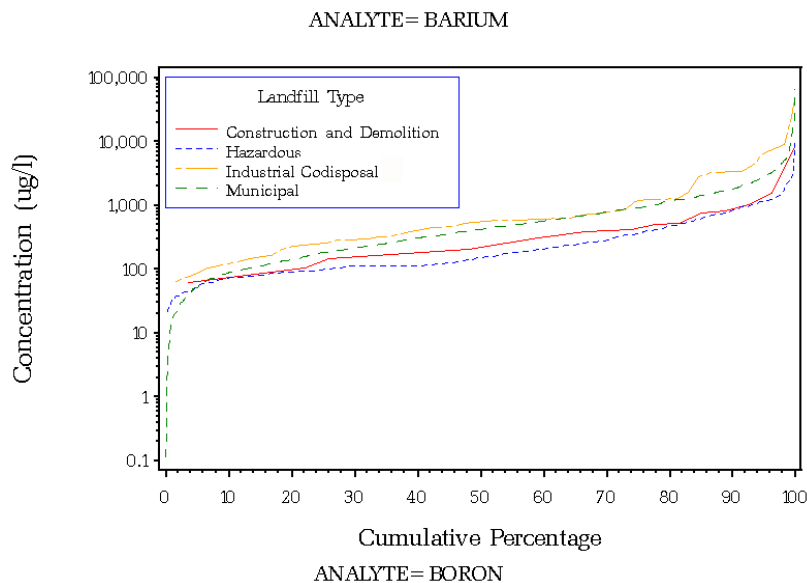


Figure 3-18. Cumulative Distribution of Other Trace Inorganics by Landfill Type

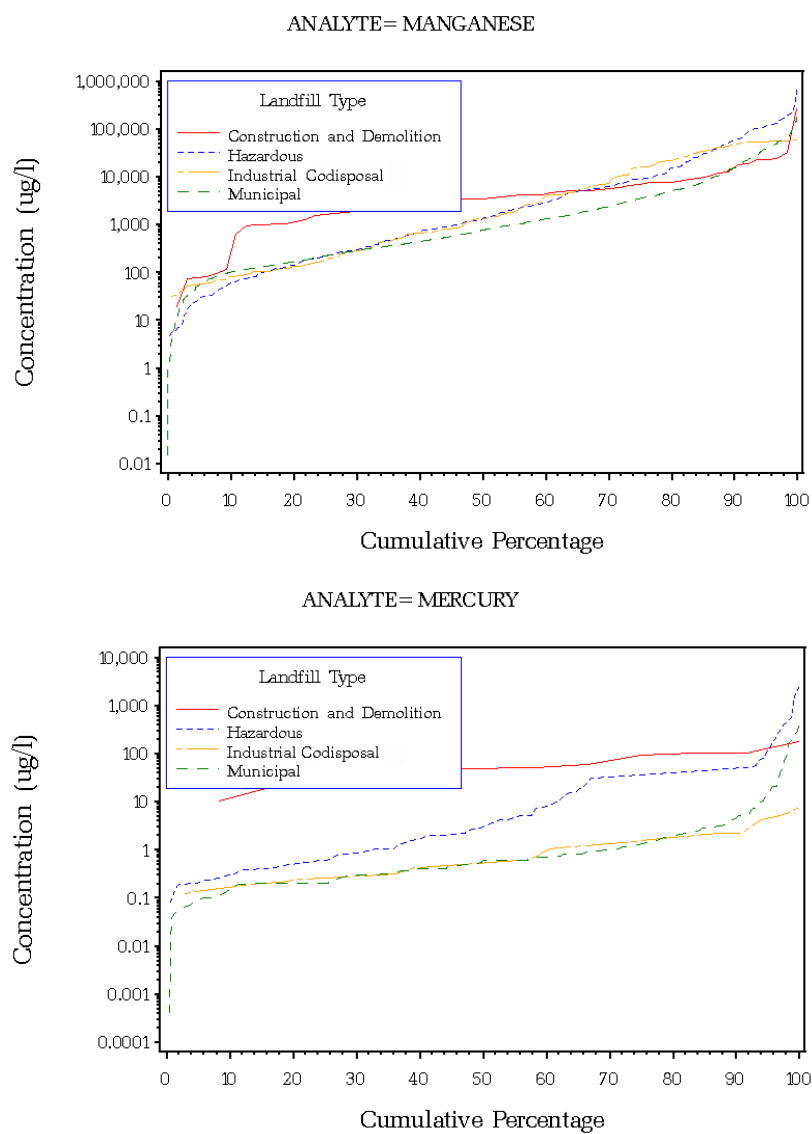


Note for aluminum: industrial codisposal data consist of only 4 observations.



Note for Boron: data for industrial codisposal and C&D consist of only 8 and 2 observations, respectively.

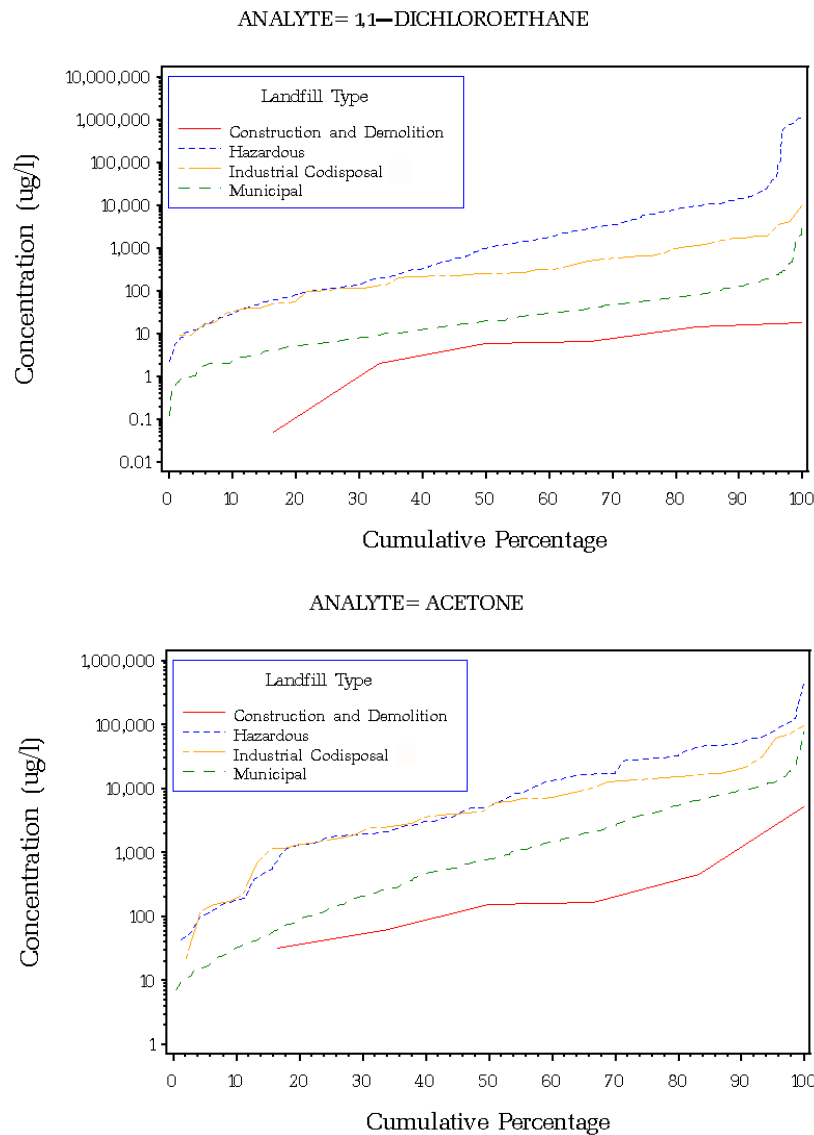
Figure 3-18. Cumulative Distribution of Other Trace Inorganics by Landfill Type
(continued)



3.6.6 Comparison of Organic Species

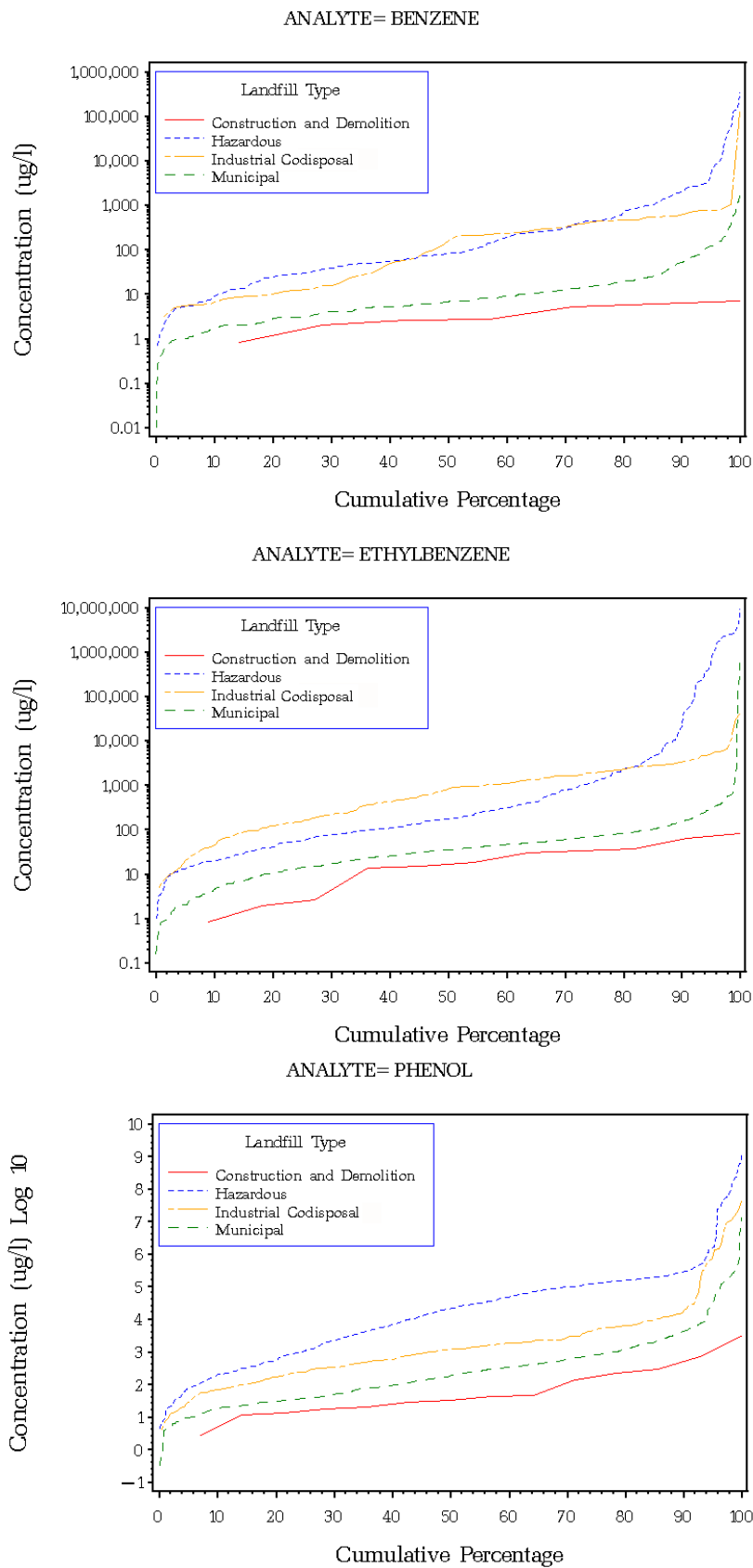
Comparison of organics concentrations is difficult because few individual organic species are analyzed and detected across all types of landfills. For C&D landfills, in fact, the number of organics data points is insufficient to draw conclusions with any confidence. Figure 3-19, however, compares concentrations for those specific organic species that are detected with frequency (greater than 25 percent of the time) in all landfill types. Based on Figure 3-19, most species appear to follow the following pattern: highest concentrations in hazardous waste landfill leachate, second highest concentrations in industrial codisposal landfill leachate, and lowest concentrations in MSW landfill leachate. Possible exceptions appear to be benzene, ethylbenzene, naphthalene, and xylene which may be higher in certain industrial codisposal landfills.

Figure 3-19. Cumulative Distribution of Organics by Landfill Type



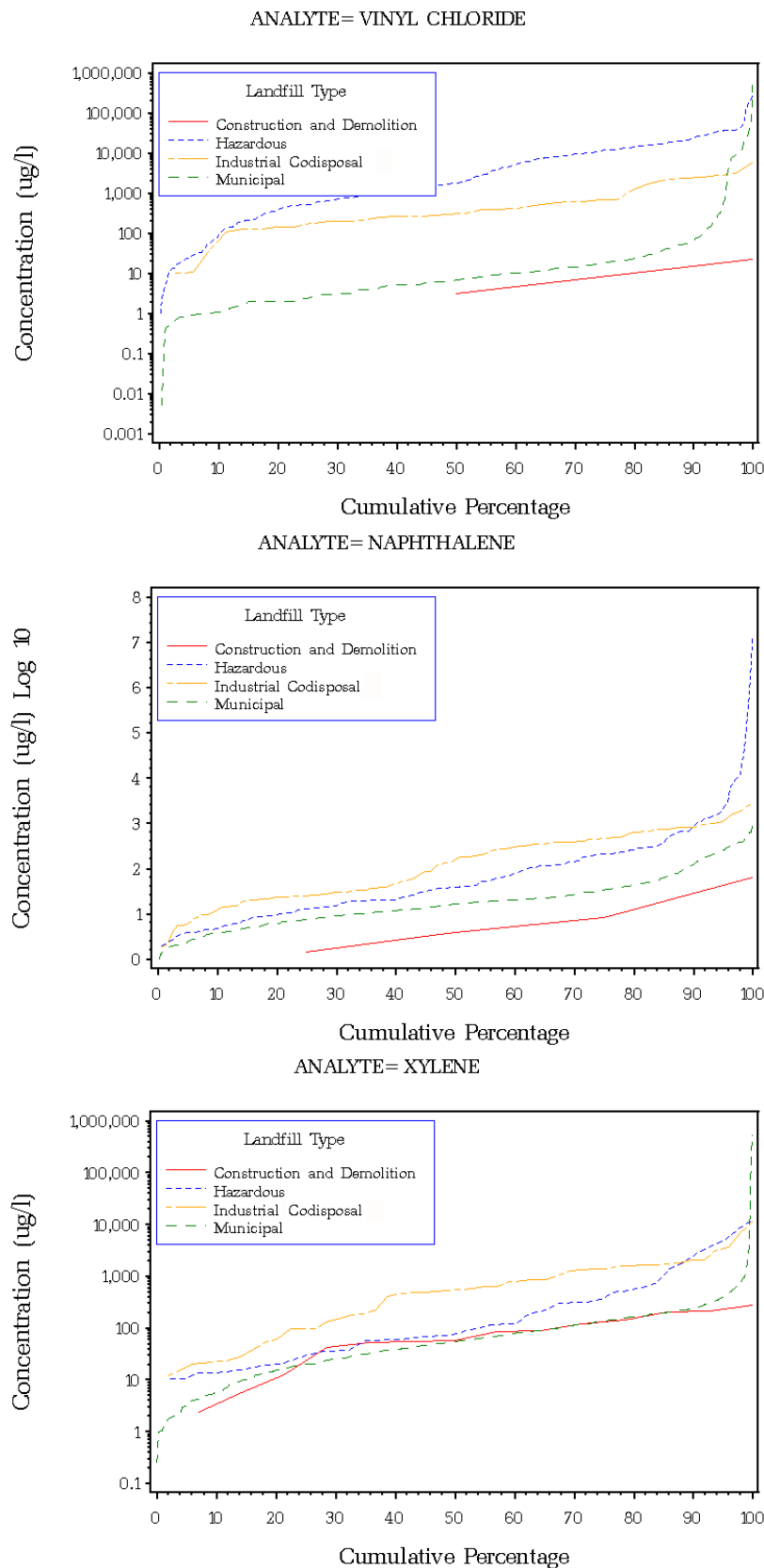
Note: for all organic species, data for C&D landfills consist of less than 15 observations

Figure 3-19. Cumulative Distribution of Organics by Landfill Type (continued)



Note: for all organic species, data for C&D landfills consist of less than 15 observations

Figure 3-19. Cumulative Distribution of Organics by Landfill Type (continued)



Note: for all organic species, data for C&D landfills consist of less than 15 observations

3.7 Summary Statistics for Captive Landfills

Included in the LEACH 2000 database are a number of landfills that do not fit the landfill categories discussed at length in preceding sections. These landfills are captive landfills that manage waste from a single industrial plant or several industrial plants owned by the same company. Detailed data are not available on the operating practices of all of these landfills, but it is believed that some may be monofills (i.e., they manage primarily a single type of waste). Even those captive landfills that are not monofills, however, would be expected to be distinctly different and possibly exhibit less variation in leachate characteristics than the landfills discussed above.

Captive landfills are discussed in this section according to the waste generating industry to which they belong. The number of captive landfills of any given type represented in the database is small. Furthermore, all of these captive landfills are in the State of Wisconsin. Therefore, the sample presented here cannot be considered statistically representative on a geographic basis. As a result, only limited efforts have been made to draw conclusions about these classes of landfills or compare across landfill types. The sections below focus instead on presenting summary statistics drawn from the available data for each type of landfill.

3.7.1 Paper Mill Landfills

The LEACH 2000 database includes data for 18 landfills that are operated by paper mills. Such landfills would be expected to receive primarily sludge and other waste from the paper making process. Leachate from paper mill landfills, therefore, would be expected to contain high levels of biodegradable organic materials. Section 4 of this report provides two specific examples of paper mill landfill operations (case studies 5 and 12).

Table 3-6 presents the available data for paper mill landfills. As expected, TOC levels in paper mill landfill leachate are higher than those for other types of landfills. In addition, BOD and COD levels are less variable and generally higher than those for other types of landfills. With the exception of boron, median metals concentrations are similar to those for MSW landfills. Organic species are infrequently detected in the available data for paper mill landfills.

3.7.2 Combustion Waste Landfills

The LEACH 2000 database includes data for six landfills that are operated by coal-fired electric utility power plants. Such landfills would be expected to receive primarily ash, flue gas desulfurization sludge, and other wastes from the electricity generating process. Leachate from these landfills, therefore, would be expected to contain non-combustible inorganics with few combustible organics. Leachate might also be expected to be alkaline because of the characteristics of coal fly ash. Section 4 of this report provides several specific examples of combustion waste landfill operations (case studies 2, 3, 4, 7, and 14).

Table 3-7 presents the available data for combustion waste landfills. As expected, median and high-end pH levels are higher than those for other types of landfills. BOD and COD levels are low compared to those for MSW landfills. With the exceptions of boron and manganese, median

inorganics concentrations, however, are not substantially different than those for MSW landfills. Organic species are rarely analyzed in the available data.

Table 3-6. Composition of Paper Mill Landfill Leachate

Analyte	N	% Detected	5th %ile	10th %ile	Median	Mean	90th %ile	95th %ile
MAJOR PHYSICAL/CHEMICAL PARAMETERS (mg/L, except pH in Standard Units)								
Alkalinity	1,479	99.9	113	264	1,575	2,630	7,050	9,000
B.O.D.	1,446	89.9	3	6.15	64.5	1,498	3,012	7,465
Calcium	363	100.0	25	47.6	168	253	441	625
Chloride	2,412	99.5	5	9.5	122	247	620	875
C.O.D.	2,089	97.2	14	29	386	2,720	7,743	15,400
Cyanide	30	46.7	0.003	0.004	0.0225	0.453	0.09	6
Fluoride	26	61.5	0.021	0.036	0.21	1.75	7.25	17
Iron	1,857	98.7	0.25	0.7	15	187	120	240
Magnesium	171	100.0	9.1	31	105	478	1,850	2,610
Nitrogen	1,075	99.7	0.36	0.82	65.5	347	980	2,000
pH	2,552	100.0	5.80	6.10	6.90	7.02	8.00	8.40
Sodium	601	100.0	13	20	130	884	1,200	2,300
Sulfate	1,668	95.4	8	13	80	221	600	1,000
T.O.C.	42	95.2	5.37	6.46	178	878	3,750	4,050
TRACE INORGANICS (µg/L)								
Aluminum	48	93.8	14	28	160	1,100	3,050	3,780
Arsenic	253	61.7	3	5.40	18.2	82.7	130	450
Barium	321	93.5	24	43.5	300	722	1,650	2,250
Boron	684	81.6	65	100	680	2,973	5,300	7,400
Cadmium	163	32.5	0.221	0.3	10	48.6	40	110
Chromium	323	48.6	2	3	15	95.2	101	150
Copper	161	65.2	7.8	10	32	275	200	1,000
Lead	152	36.8	1.42	2.90	17.5	218	270	490
Manganese	384	99.2	59	100	1,330	5,627	12,300	22,000
Mercury	212	25.9	0.05	0.06	0.2	0.628	1.9	3
Nickel	105	70.5	13	18	59	93.2	180	230
Selenium	139	20.9	1	2	7.3	42.0	136	320
Silver	107	21.5	1.4	1.5	10	18.5	40	74
Zinc	170	76.5	7	10	35	147	205	420
ORGANICS (µg/L)								
1,1-Dichloroethane	90	3.3	1.1	1.1	1.2	1.63	2.60	2.60
Acenaphthene	27	3.7	1,900	1,900	1,900	1,900	1,900	1,900
Benzene	90	6.7	0.24	0.24	1.19	1.68	3.4	3.4
Ethylbenzene	90	11.1	0.28	0.29	1.35	3.31	12.2	22
Naphthalene	62	21.0	1.1	1.1	5.60	82.1	140	720
Phenol	26	19.2	9.2	9.2	150	179	490	490
Trichloroethylene	89	6.7	0.68	0.68	17	58.3	280	280
Vinyl Chloride	86	1.2	0.46	0.46	0.46	0.46	0.46	0.46
Xylene	123	14.6	0.19	0.28	2.1	27.9	14	440

Source: Characterization data from the 18 paper mill landfills included in the LEACH 2000 database.

Table 3-7. Composition of Combustion Waste Landfill Leachate

Analyte	N	% Detected	5th %ile	10th %ile	Median	Mean	90th %ile	95th %ile
MAJOR PHYSICAL/CHEMICAL PARAMETERS (mg/L, except pH in Standard Units)								
Alkalinity	145	100.0	35	41	120	313	505	1,732
B.O.D.	88	42.1	0.21	2	9.6	22.9	48.8	130
Calcium	66	100.0	28.2	38	236	278	540	570
Chloride	71	98.6	1.7	7.38	52	139	354	960
C.O.D.	106	69.8	4.1	5	12	126	210	580
Fluoride	2	100.0	0.15	0.15	0.26	0.26	0.37	0.37
Iron	114	84.2	0.02	0.05	1.3	5.40	13.5	28
Magnesium	45	95.6	4.45	5.7	53.5	114	100	110
Nitrogen	13	23.1	0.76	0.76	0.81	0.857	1	1
pH	158	98.7	5.80	6.36	7.70	8.10	11.45	12.09
Sodium	58	100.0	25	56	290	265	430	480
Sulfate	146	100.0	154	373	1,285	1554.7728	2400	3900
TRACE INORGANICS (µg/L)								
Arsenic	19	63.2	2	3.1	8.15	34.8	80	140
Barium	48	85.4	12	16	74	99.7	202	260
Boron	145	97.9	240	1,840	20,500	36,951	99,000	130,000
Cadmium	60	73.3	0.566	1.6	4.42	5.71	9.6	14.7
Chromium	44	79.6	2	4	10.9	72.4	134	600
Copper	18	55.6	3	5.5	35	48.0	122	175
Lead	38	47.4	1	1.5	5.85	11.6	30	60
Manganese	50	94.0	11	53	6,400	5,987	13,000	14,000
Mercury	24	25.0	0.2	0.2	0.55	0.95	3	3
Nickel	14	85.7	12	32	103.5	149	360	510
Selenium	117	94.0	2.4	3.8	19.5	111	99.5	170
Silver	19	10.5	0.2	0.2	10.1	10.1	20	20
Zinc	43	90.7	109	210	377	1,003	1,100	1,700
ORGANICS (µg/L)								
Phenol	5	20.0	24	24	24	24	24	24

Source: Characterization data from the six electric utility landfills included in the LEACH 2000 database.

3.7.3 Foundry Landfills

The LEACH 2000 database includes data for three landfills that are operated by foundries. Such landfills would be expected to receive metal-bearing waste from production and pollution control processes. Leachate from these landfills, therefore, would be expected to be relatively high in metals and contain few combustible organics. Section 4 of this report includes a specific example of a foundry landfill operation (case study 16).

Table 3-8 presents the available data for foundry landfills. As expected, BOD levels are lower than those for MSW landfills. With the possible exception of nickel, however, metals levels are not significantly different from those in MSW landfills. Median fluoride, sodium, and sulfate concentrations are substantially higher than those in MSW landfills.

Table 3-8. Composition of Foundry Landfill Leachate

Analyte	N	% Detected	5th %ile	10th %ile	Median	Mean	90th %ile	95th %ile
MAJOR PHYSICAL/CHEMICAL PARAMETERS (mg/L, except pH in Standard Units)								
Alkalinity	101	99.0	118	128	180	185	250	290
B.O.D.	76	56.6	2	2	7	52.0	150	277
Chloride	97	100.0	110	160	445	524	770	911
C.O.D.	101	99.0	18.5	22	104	175	382	530
Cyanide	5	40.0	0.015	0.015	0.0235	0.0235	0.032	0.032
Fluoride	44	100.0	1.1	1.62	3.85	3.74	5.5	5.8
Iron	88	94.3	0.04	0.06	0.2	0.744	1.83	3.26
Nitrogen	7	100.0	0.06	0.06	0.64	0.943	3	3
pH	119	98.3	6.69	7.01	7.80	8.01	9.78	9.90
Sodium	101	99.0	240.5	325	854	921	1,505	1,980
Sulfate	101	100.0	390	530	1,580	1,686	2,799	3,130
TRACE INORGANICS (µg/L)								
Arsenic	12	16.7	1	1	9	9	17	17
Barium	15	80.0	8	24	35	37.8	60	69
Cadmium	69	36.2	0.19	0.2	10	12.3	27	41.3
Chromium	14	35.7	1.8	1.8	20	197	910	910
Copper	16	37.5	6	6	14.5	616	3,600	3,600
Lead	81	35.8	2.1	2.4	30	138	290	300
Manganese	25	80.0	20.7	45	227	478	1050	1860
Mercury	24	16.7	0.080	0.080	0.2	0.245	0.5	0.5
Nickel	16	25.0	5.7	5.7	805	954	2,200	2,200
Selenium	12	8.3	1.1	1.1	1.1	1.1	1.1	1.1
Silver	12	16.7	0.5	0.5	10.2	10.2	20	20
Zinc	17	35.3	10	10	32.5	40.7	110	110
ORGANICS (µg/L)								
Acetone	10	80.0	17	17	63	60.9	100	100
Benzene	16	43.8	0.2	0.2	0.33	14.9	100	100
Ethylbenzene	16	25.0	0.2	0.2	1.75	25.9	100	100
Methyl Isobutyl Ketone	10	10.0	1.9	1.9	1.9	1.9	1.9	1.9
Naphthalene	19	21.0	1	1	435	418	800	800
Phenol	12	8.3	190	190	190	190	190	190
Xylene	27	25.9	0.2	0.2	5	131	500	500

Source: Characterization data from the three foundry landfills included in the LEACH 2000 database.

4. QUANTITATIVE LANDFILL CASE STUDIES

Upon initiating this study it was hoped that a comprehensive database integrating landfill operations and permitting data with leachate generation data and leachate composition data could be found or created. The collection of data on leachate generation and composition met with some success, as discussed in Sections 2 and 3. No comprehensive electronic databases, however, were located containing information on landfill permitting, design, and operations, much less linking this information with leachate generation or composition data.

Therefore, to present a holistic overview of landfill design and operations in combination with leachate quantity and quality, this report relies on detailed case studies. This section presents 22 quantitative case studies highlighting pertinent data for several types of landfills. The landfill types (and number of each type) represented in the case studies are as follows: municipal solid waste (MSW) (10), ash (6), construction and demolition (C&D) (3), paper mill sludge (2), foundry (1) and Subtitle D (1). The Subtitle D landfill accepted nearly the same quantity of industrial waste as it did municipal waste. In addition, one facility operated a MSW and C&D landfills for which data was obtained.

Each case studies integrates landfill operational data (size, construction and controls, location, waste acceptance and quantities) with leachate quantity and quality data, in a front and back display, to provide an exemplary cross-section of U.S. landfills. Table 4-1 provides the index for the case studies.

Data was compiled using available data sources. These sources included, but were not limited to, EPA site visit reports as part of the Office of Water *Effluent Guidelines for Point-Source Category for Landfills: Regulatory Docket*, the Electric Power Research Institute report entitled, *Field Evaluation of the Comanagement of Utility Low-Volume Wastes with High-Volume Coal Combustion By-Products* (August, 1997) and an file review at the Wisconsin Department of Natural Resources. These data were supplemented, when possible, via personal communication.

Table 4-1. Landfill Case Studies

Case Study No.	Name	Location	Type	Data As Recent As:
1	Shrewsbury	Shrewsbury, MA	Incinerator ash monofill	1993
2	Limestone	Jewett, TX	Combustion ash monofill	1996
3	Pawnee	Brush, CO	Combustion ash monofill	pre-1997
4	Pleasant Prairie	Pleasant Prairie, WI	Combustion ash monofill	1997
5	Wisconsin Tissue Mill Vinland Site	Vinland, WI	Paper mill sludge monofill	1997
6	Superior Emerald Park	Muskego, WI	Municipal	1999
7	Wisconsin Electric and Power Co. Caledonia	Caledonia, WI	Combustion ash monofill	1997
8	Ingles Mountain	Radford, VA	Construction and demolition debris (C&D)	1999
9	La Crosse County	La Crosse, WI	Municipal	1997
10	Superior Greentree	Kersey, PA	Subtitle D	1999
11	Marathon County	Ringle, WI	Municipal	1999
12	Mead Paper	Chillicothe, OH	Paper mill sludge monofill	1993
13	Mormon Hollow Road	Wendell, MA	Construction and demolition debris (C&D)	1999
14	Northern States Power Woodfield	Ashland, WI	Combustion ash monofill	1997
15	WMWI Timberline Trail	Bruce, WI	Municipal	1997
16	Waupaca Foundry	Waupaca, WI	Foundry	1997
17	Westside	Three Rivers, MI	Municipal and construction and demolition debris (C&D)	1999
18	Winnebago County Sunnyview	Oshkosh, WI	Municipal	1997
19	Superior	Savannah, GA	Municipal	1994
20	Northwoods Sanitary	Rice Lake, WI	Municipal	1997
21	Vernon County	Viroqua, WI	Municipal	1997
22	Tangipahoa Parish	Independence, LA	Municipal	1994

LANDFILL CASE 1: SHREWSBURY ASH MONOFILL

Identification

Name: Shrewsbury Residue Landfill
 Address: 640 Hartford Tnpk (US 20)
 Shrewsbury, MA 01545
 Owner/Operator: Town of Shrewsbury/Wheelabrator Millbury Inc. and A.J. Letourneau
 Dispose-All Company
 Ownership status: Commercial
 Facility contact: Steve Sibinich, Director EH&S Compliance 508-791-8900
 Alfred Confalone, Manager
 Discharge permit no.: 120
 State permit no.: BWP SW09
 Landfill type: Incinerator ash landfill
 Permitting status: Active

Landfill Construction and Controls

Type of LCS: Network of slotted polyvinyl chloride piping placed into a sand drainage blanket
 Number of sections: Four (4)
 Status: Section 1—closed, Section 2—active, Sections 3 and 4—not constructed
 Liner type: Two feet of compacted clay overlain by a geomembrane consisting of 60 mil HDPE
 Cover type: Six inch daily soil cover
 Operational period: 1989 to present
 Waste acceptance: Fly and bottom ash, residual wastes (such as bar screenings and grit), and street cleaning wastes
 Overall location area: 45 acres
 Total permitted area: 36.6 acres
 Total landfill capacity: 2,933,000 yd³

Landfilled Waste

Nature of waste: Incinerator residue, street cleaning waste, waste water treatment plant (WWTP) waste
 Annual landfilled quantity: 155,000 tons (1993)
 Total cumulative landfilled quantity: 944,200 tons (as of 1993)
 Liquid to solid ratio: Approximately 0.044 L/kg

Leachate Quantity

Annual leachate generation: 10,942,381 gallons (1993)
 Average annual precipitation: 46.48 inches

Exhibit 1. Landfill Construction and Controls			
Section/ Cell	Status	Area (acres)	Design Capacity (yd ³)
1	Closed with geomembrane cover (full)	10.5	469,000
2	Active (60% of capacity)	11.5	792,000
3	Not constructed	6.6	847,000
4	Not constructed	8.0	825,000
Totals		36.6	2,933,000
Averages		9.2	733,250

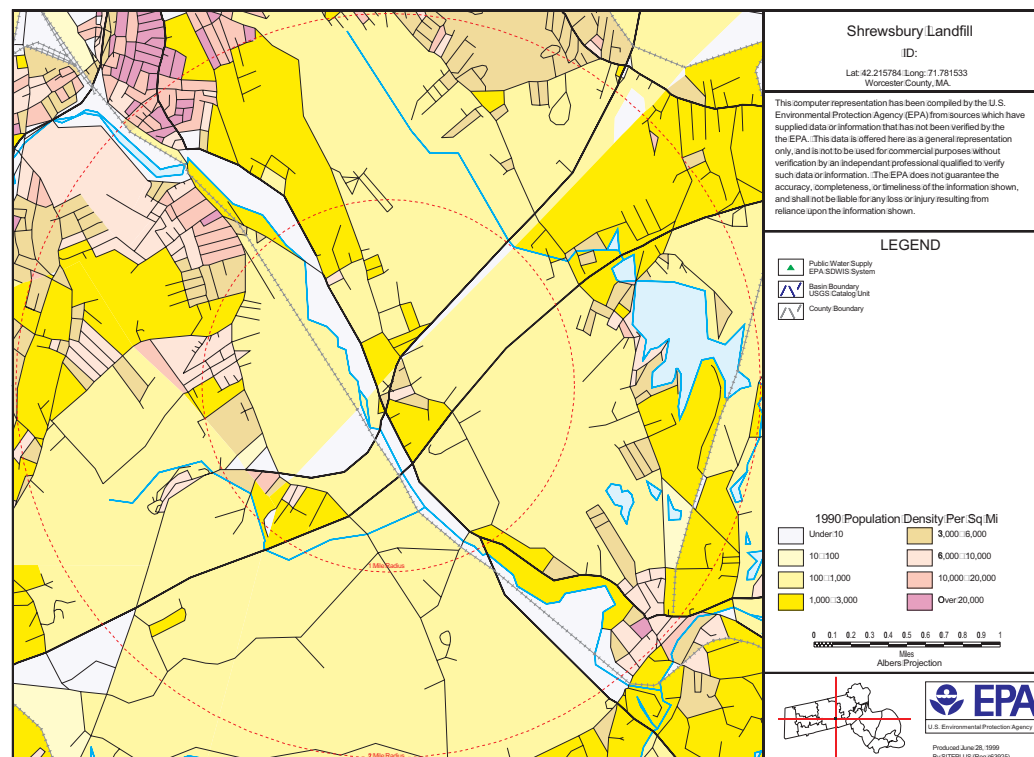


Exhibit 2. Waste Data			
Wastes Accepted	Constituents	Average Daily Quantity (tons)	Percentage of Total by Weight
Incinerator Residue	Air Pollution Control Hopper Ash	31.5	9
	Bottom Ash	287	82
	Fly Ash	24.5	7
	Sifting and Riddlings	7	2
Street Cleaning Waste	N/A	1.37	<0.4
WWTP Wastes	N/A	0.27	<0.08
Totals		351.64	100

Exhibit 3. Leachate Quantity Summary (based on 1993 Data)				
Quarter	Dates	Precipitation (inches)	Leachate Quantity (gal.)	Daily Average
1	January–March	10.4	2,884,122	32,406
2	April–June	8.15	2,784,440	30,598
3	July–September	14.09	1,547,656	16,822
4	October–December	13.84	3,726,163	40,502
Totals		46.48	10,942,381	30,061

Leachate Quality

Exhibit 4. Leachate Composition Data					
PARAMETER	Concentration (ug/l)				
	OBS	10 th	50 th	90 th	MAX
PHYSICAL/CHEMICAL CHARACTERISTICS					
BOD	16	22	36	77	151
COD	17	37	247	649	800
TDS	17	2700	8590	9540	48500
pH (su)	17	6	6.5	8.1	8.3
Nitrate/Nitrite	1	14	14	14	14
Total Phenols	1	4.34	4.34	4.34	4.34
Total Sulfide (Iodometric)	1	80	80	80	80
Alkalinity	4	59	77.3	84	114
Acidity	4	16	23.5	20	46
Sulfate	4	136	131	145	175
FOG	6	0.8	47.3	16	250
Specific Conductivity	4	10900	11000	11700	12300
TSS	16	10	62.6	137	350
TRACE CONTAMINANTS					
Metals					
Antimony	1	0.131	0.131	0.131	0.131
Barium	5	1.16	2.82	2.6	6.99
Beryllium	1	0.0672	0.0672	0.0672	0.0672
Boron	14	0.05	0.274	0.328	2.15
Cadmium	6	0.007	0.0372	.02	0.172
Calcium	5	1400	3570	2300	11400
Chloride	5	3760	9250	4890	29900
Chromium	1	0.022	0.022	0.022	0.022
Copper	15	0.02	0.122	0.377	0.47
Europium	1	0.298	0.298	0.298	0.298
Fluoride	1	0.38	0.38	0.38	0.38
Iridium	1	1.01	1.01	1.01	1.01
Iron	5	2.53	3.51	4.41	5.56
Lead	8	0.009	10.3	0.28	81.4
Magnesium	4	4.78	4.90	6.03	6.29
Manganese	5	1.41	4.28	4.09	12.7
Molybdenum	11	0.01	0.0762	0.06	0.536
Nickel	5	0.035	0.104	0.184	0.201

Niobium	1	1.15	1.15	1.15	1.15
Platinum	1	1.46	1.46	1.46	1.46
Potassium	5	426	1130	975	2950
Samarium	1	2.13	2.13	2.13	2.13
Scandium	1	0.0505	0.0505	0.0505	0.0505
Silicon	1	25.0	25.0	25.0	25.0
Silver	3	0.015	0.0187	0.015	0.03
Sodium	5	655	1750	1440	4890
Strontium	1	58.0	58.0	58.0	58.0
Sulfate	4	136	130.5	145	175
Sulfur	1	628	628	628	628
Tantalum	1	1.14	1.14	1.14	1.14
Zinc	11	0.03	0.164	0.596	0.652

Data Source

Effluent Guidelines for Landfill Point Source Category: Shrewsbury Site Visit Report, April 5, 1995.

LANDFILL CASE 2: LIMESTONE COMBUSTION ASH MONOFILL

Identification

Name: Limestone Station Ash Landfill
 Address: Jewett, T 75846
 Owner/Operator: Houston Power and Light
 Ownership status: Captive
 EPA ID: T D987978210
 Landfill types: Industrial (Coal combustion ash)
 Permitting status: Active

Landfill Construction and Controls

Type of LCS: Impermeable trench surrounding landfill to intercept stormwater runoff and leachate.
 Number of cells: 20
 Waste acceptance: Coal combustion ash and low-volume solid waste
 Overall location area: 380 acres
 Permitted area: Unknown
 Cell dimensions: Cells 1, 2, 3, 4, and 6 total 68 acres. Peak landfill height approximately 120 feet above grade.
 Cell capacity: Unknown
 Run-on/off controls: Diversion ditches carry runoff to a sedimentation pond.
 Underlying geology/soil type: 50 feet of alluvium (sand, silt, and clay), underlain by 20 feet of sand, underlain by 600 feet of interbedded muds, sands, and lignite deposits.
 Depth to aquifer: Approximately 5–10 feet below liner.
 Special Practices: None noted.

Landfilled Waste

Nature of waste: Coal combustion waste (fly ash, bottom ash, flue gas desulfurization sludge) managed with low-volume solid wastes.

Annual quantity landfilled: 1,790,000 tons (1996)
 Total cumulative landfilled quantity: 19.7 million tons of coal combustion waste through 1996
 Liquid to solid ratio: Unknown

Leachate Quantity

Average leachate generation: No data.
 Average annual precipitation: 32 inches

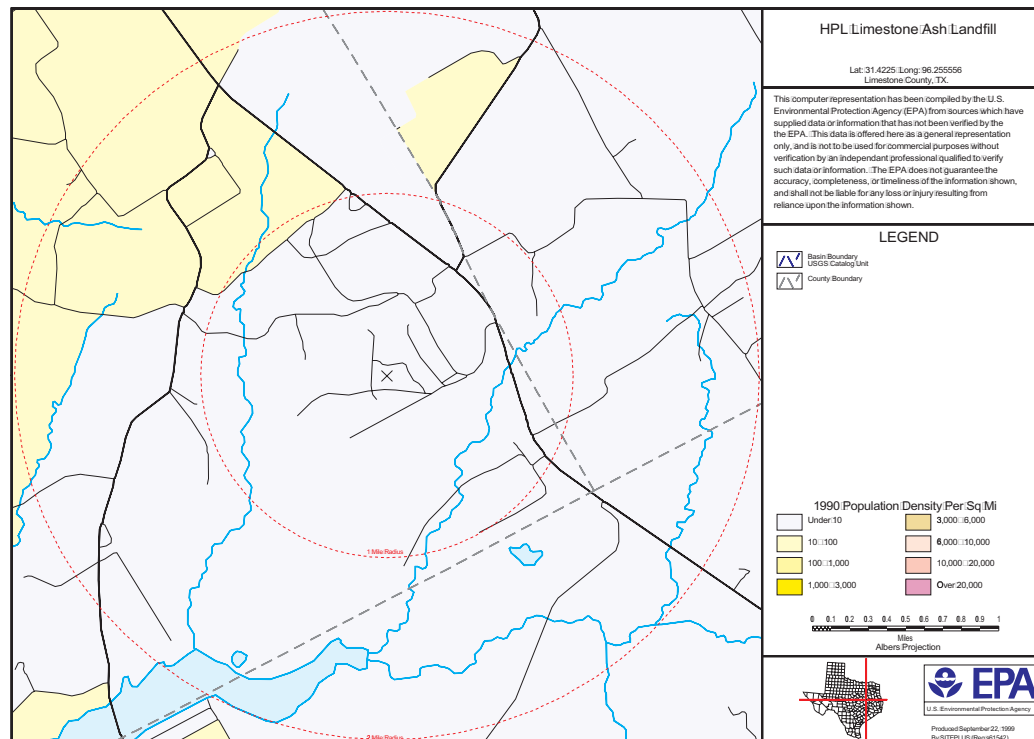


Exhibit 1. Landfill Construction and Controls						
Landfill Type/Area	Cell(s)	Status	Liner	LCS	Cover	Operational Period
Coal combustion ash/380 acres	1, 2, 3, 4, 6	Closed	3-foot thick compacted clay	Impermeable trench surrounding landfill (stormwater and leachate)	3-foot clay cap overlain by topsoil	1986–()
	5	Active			None	()–Present
	6–20	Proposed			N/A	N/A

Exhibit 2. Waste Data		
Wastes Accepted	Quantity in 1996 (tons)	Percentage of Total Weight
Fly ash	840,000	47
Bottom ash/boiler slag	397,000	22
Flue gas desulfurization sludge	500,000	28
Mill rejects	36,500	2
Water treatment pond sludges	12,710	<1
Cooling tower sludge	480	<1
Filter bed media	10	<1
Spent demineralizer resin beads	5	<1
Sandblast grit	100	<1
Cooling tower fill	40	<1
Refractory brick	5	<1

Leachate Quality

Exhibit 3. Leachate Composition Data*							
PARAMETER	Concentration (ug/l)						
	OBS	10th	50th	90th	MAX	% Detect	Avg DL
PHYSICAL/CHEMICAL PROPERTIES							
IC	1	8,540	8,540	8,540	8,540	100	Unknown
DOC	1	22,600	22,600	22,600	22,600	100	Unknown
pH (SU)	1	8.38	8.38	8.38	8.38	100	Unknown
Eh (mV)	1	-332	-332	-332	-332	100	Unknown
EC (us/cm)	1	7.56	7.56	7.56	7.56	100	Unknown
INORGANICS/TRACE ELEMENTS							
Aluminum	1	640	640	640	640	100	Unknown
Arsenic	1	11.4	11.4	11.4	11.4	100	Unknown
Barium	1	191	191	191	191	100	Unknown
Boron	1	28,700	28,700	28,700	28,700	100	Unknown
Bromine	1	101,000	101,000	101,000	101,000	100	Unknown
Cadmium	1	<2.5	<2.5	<2.5	<2.5	100	Unknown
Calcium	1	749,000	749,000	749,000	749,000	100	Unknown
Chloride	1	1,312,000	1,312,000	1,312,000	1,312,000	100	Unknown
Chromium	1	<2.5	<2.5	<2.5	<2.5	100	Unknown
Copper	1	<10	<10	<10	<10	100	Unknown
Fluoride	1	<2,000	<2,000	<2,000	<2,000	100	Unknown
Iron	1	ND	ND	ND	ND	0	Unknown
Lead	1	<5	<5	<5	<5	100	Unknown
Magnesium	1	19,500	19,500	19,500	19,500	100	Unknown
Manganese	1	563	563	563	563	100	Unknown
Molybdenum	1	ND	ND	ND	ND	0	Unknown
Nickel	1	34.2	34.2	34.2	34.2	100	Unknown
NO2	1	<2,000	<2,000	<2,000	<2,000	100	Unknown
NO3	1	<300	<300	<300	<300	100	Unknown
Potassium	1	84,500	84,500	84,500	84,500	100	Unknown
PO4	1	<500	<500	<500	<500	100	Unknown
Selenium	2	ND	--	128	128	50	Unknown
Silicon	1	5,800	5,800	5,800	5,800	100	Unknown
Silver	1	<1	<1	<1	<1	100	Unknown
Sodium	1	742,000	742,000	742,000	742,000	100	Unknown
Strontium	1	23,000	23,000	23,000	23,000	100	Unknown
Sulfur	1	721,000	721,000	721,000	721,000	100	Unknown
SO3	1	<5,000	<5,000	<5,000	<5,000	100	Unknown
SO4	1	2,051,000	2,051,000	2,051,000	2,051,000	100	Unknown
S203	1	13,900	13,900	13,900	13,900	100	Unknown
Vanadium	1	4.51	4.51	4.51	4.51	100	Unknown
Zinc	1	116	116	116	116	100	Unknown

* Based on samples of seepage from landfill to leachate/runoff drainage ditch.

Data Source

Field Evaluation of the Comanagement of Utility Low-Volume Wastes with High-Volume Coal Combustion By-Products: LS Site. Electric Power Research Institute. Final Report, August 1997.

LANDFILL CASE 3: PAWNEE ASH MONOFILL

Identification

Name: Pawnee Station Ash Landfill
 Address: 14940 County Road 24
 Brush, CO 80723
 Owner: Public Service Company of Colorado
 Ownership status: Captive
 EPA ID: COD98028025
 NPDES ID: CO 600195
 Landfill type: Industrial (Coal combustion ash)
 Permitting status: Active

Landfill Construction and Controls

Type of LCS: None
 Number of cells: 1
 Liner type: 2-foot compacted locally derived fine sand to clay.
 Operational period: 1980 to present
 Waste acceptance: Coal combustion ash and low-volume solid wastes
 Overall location area: 20 acres
 Permitted area: 20 acres
 Landfill dimensions: Landfill excavated to 42 feet below ground level. Maximum thickness approximately 40 feet.
 Landfill capacity: Unknown
 Run-on/off controls: None identified
 Underlying geology/soil type: Dune sand, overlying less than 24 feet of residual soil (very fine sand and silt with up to 30 percent clay), overlying bedrock at 50–75 feet below the ground surface.
 Depth to aquifer: Water table is above the excavated depth of the landfill.
 Special practices: Surface water from precipitation and natural dewatering of sludge waste collects in a topographic low area of the landfill.

Landfilled Waste

Nature of waste: Coal combustion waste (fly ash, bottom ash, and boiler slag) comanaged with low-volume solid wastes.
 Average annual quantity landfilled: Approximately 675,000 yd³
 Total cumulative quantity landfilled: Unknown
 Liquid to solid ratio: Unknown

Leachate Quantity

Average leachate generation: No data (leachate not collected)
 Average annual precipitation: 15 inches rain, 60 inches snow

Leachate Quality

No data are available for leachate as generated. Data are available, however, in the EPRI report characterizing 2:1 distilled water extracts from waste as managed in the landfill.

Data Source

Field Evaluation of the Comanagement of Utility Low-volume Wastes with High-volume Coal Combustion By-Products: PA Site. Electric Power Research Institute. Draft Report, August 1997.

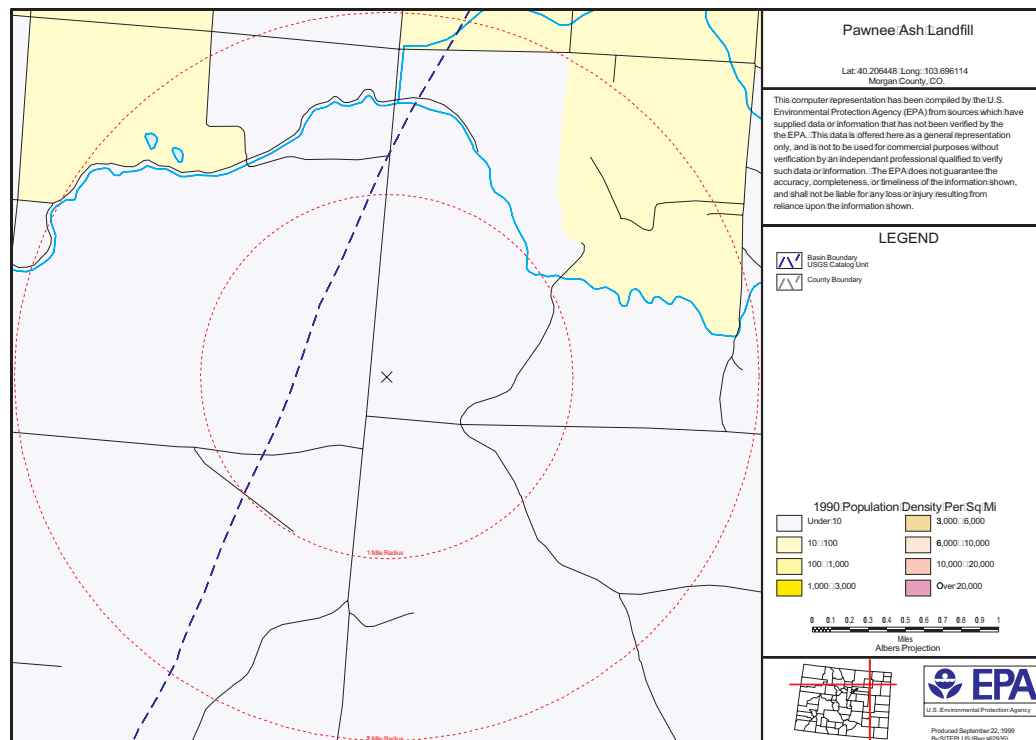


Exhibit 1. Waste Data		
Wastes Accepted	Quantity (cubic yards/year)	Percentage of Total Weight
Fly ash	46,000	6.8
Boiler slag	50	<0.1
Water treatment wastes (thickener sludge)	569,000	84.0
Cooling tower sludge	20,000	3
High-quality holding basin sludge	30	<0.1
Wastewater treatment sludge (brine decant pit sludge)	36,000	5.3
Refractory brick	200	<0.1
Miscellaneous wastes	4,000	0.6

LANDFILL CASE 4: PLEASANT PRAIRIE ASH MONOFILL

Identification

Name: Pleasant Prairie Ash Landfill
 Address: 8000 95 Street
 Pleasant Prairie, WI 53201
 Owner: Wisconsin Electric Power Company
 Ownership status: Captive
 EPA ID: WID000711176
 NPDES ID: WI0043583
 Landfill type: Industrial (Coal combustion ash)
 Permitting status: Active

Landfill Construction and Controls

Type of LCS: None
 Number of cells: 25
 Waste acceptance: Coal combustion ash and low-volume solid wastes
 Overall location area: 163 acres
 Permitted area: 163 acres
 Landfill dimensions: Each cell approximately 6 acres. Maximum thickness of closed cells estimated 25 feet.
 Landfill capacity: Unknown
 Run-on/off controls: Retention and drainage ditches from which runoff evaporates or infiltrates into the ground.
 Underlying geology/soil type: Less than 1 foot of topsoil (silty clay and silt loam), underlain by glacial drift (till, clay, silt, sand, and some gravel), underlain by bedrock (105–120 feet below ground surface).
 Depth to aquifer: Approximately 2–8 feet below base of waste.
 Special practices: Bottom ash and boiler slag spread in cell base, fly ash and low-volume solids placed on top, spread, and compacted following the addition of treated cooling tower water for dust suppression.

Landfilled Waste

Nature of waste: Coal combustion waste (fly ash, bottom ash, and boiler slag) comanaged with low-volume solid wastes.
 Average annual quantity landfilled: 35,000 yd³
 Total cumulative quantity landfilled: 595,462 yd³ (through mid-1997)
 Liquid to solid ratio: Unknown

Leachate Quantity

Leachate generation: Unknown (leachate not collected)
 Average annual precipitation: 33 inches

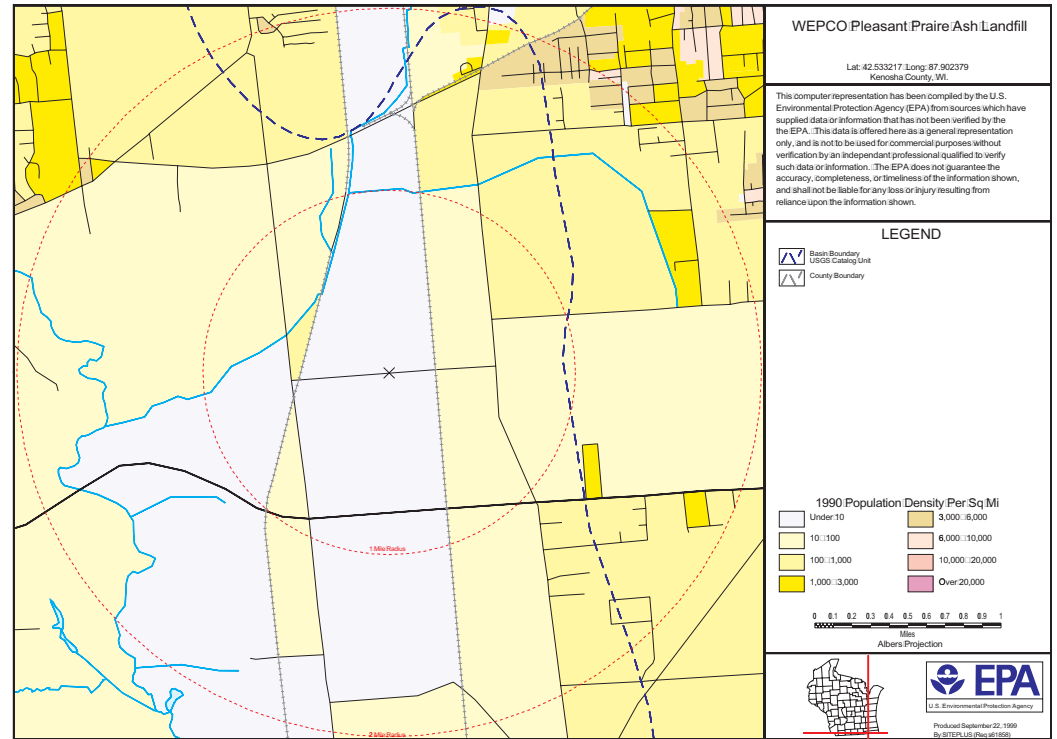


Exhibit 1. Landfill Construction and Controls

Landfill Type/Area	Cell(s)	Status	Liner	LCS	Cover	Operational Period
Coal combustion ash/163 acres	1	Closed	Compacted soil only	None	2-foot clay cap overlain by 6 inches topsoil	1980–1986
	2	Closed	5-feet thick clay over compacted soil	None	2-foot clay cap overlain by 6 inches topsoil	1985–1991
	3	Closed	5-feet thick clay over compacted soil	None	2-foot clay cap overlain by 6 inches topsoil	1988–1994
	4	Active	5-feet thick clay over compacted soil	None	None	1994–Present
	5–25	Permitted, not yet developed	N/A	N/A	N/A	N/A

Exhibit 2. Waste Data

Wastes Accepted	Quantity (cubic yards/year)	Percentage of Total Weight
Fly ash	5,000	14.4
Economizer Ash	300	0.9
Bottom Ash and Boiler Slag	29,000	83.2
Low-volume Waste Basin Sludge	75	0.2
Metal Cleaning Waste Basin Sludge	100	0.3
Coal Pile Runoff Basin Sludge	150	0.4
Wastewater Treatment Sludge	200	0.6
Cooling Tower Basin Sludge	20	<0.1
Scrap Ferrous Metal and Waste Sulfite	1	<0.1

Leachate Quality

Exhibit 3. Leachate Composition Data*						
PARAMETER	Concentration (ug/l)					
	OBS	MIN	Average	MAX	% Detect	Avg DL
PHYSICAL/CHEMICAL PROPERTIES						
TDS	Unknown	2,130,000	2,716,000	3,200,300	Unknown	Unknown
Alkalinity	Unknown	49,000	451,000	1,284,000	Unknown	Unknown
pH (SU)	Unknown	9.22	11.5	12.59	Unknown	Unknown
EC (us/cm)	Unknown	2,961	4,305	6,600	Unknown	Unknown
INORGANICS/TRACE ELEMENTS						
Arsenic	Unknown	1	10	28	Unknown	Unknown
Barium	Unknown	10	5,320	24,100	Unknown	Unknown
Boron	Unknown	1,060	3,250	5,970	Unknown	Unknown
Cadmium	Unknown	<3	70	71	Unknown	Unknown
Calcium	Unknown	1,670	161,000	530,000	Unknown	Unknown
Chloride	Unknown	12,890	56,000	160,490	Unknown	Unknown
Chromium	Unknown	<3	0	16	Unknown	Unknown
Copper	Unknown	2	20	53	Unknown	Unknown
Fluoride	Unknown	209	430	880	Unknown	Unknown
Iron	Unknown	10	230	890	Unknown	Unknown
Lead	Unknown	2	10	20	Unknown	Unknown
Magnesium	Unknown	10	1,200	8,290	Unknown	Unknown
Manganese	Unknown	5	710	3,790	Unknown	Unknown
Molybdenum	Unknown	520	1,070	1,620	Unknown	Unknown
NO3	Unknown	90	1,000	3,670	Unknown	Unknown
Potassium	Unknown	19,380	52,800	115,500	Unknown	Unknown
Selenium	Unknown	2	860	12,850	Unknown	Unknown
Silver	Unknown	1	0	2	Unknown	Unknown
Sodium	Unknown	388,000	732,000	1,263,000	Unknown	Unknown
SO4	Unknown	694,000	1,446,000	1,952,000	Unknown	Unknown
Zinc	Unknown	10	30	77	Unknown	Unknown

* Data shown are based on summary data for aqueous samples from four leachate head wells taken between 1978 and 1997. Because the individual sample data and number of observations were not reported, 50th and 95th percentile values could not be determined.

Data Source

Field Evaluation of the Comanagement of Utility Low-Volume Wastes with High-Volume Coal Combustion By-Products: P4 Site. Electric Power Research Institute. Final Report, July 1997.

LANDFILL CASE 5: WTM INLAND SITE PAPER MILL SLUDGE E MONOFILL

Identification

Name: WTM inland Site Paper Mill Sludge Monofill
 Address: US Highway 45 and County Truck Highway inland, WI
 Owner: Wisconsin Tissue Mills (WTM)
 Ownership status: Captive
 Facility contact: Bernie opp, P-Tech Development, 414-725-7031
 State license no.: 03131
 Landfill type: Industrial (Pulp/paper sludge)
 Permitting status: Closed

Landfill Construction and Controls

Type of LCS: Standard
 Number of phases: Two (2)
 Status: Closed
 Liner type: 5-feet of compacted clay
 Final cover: Clay overlain by top soil
 Operational period: February 1988 to June 1997
 Waste acceptance: Pulp and paper mill sludge from WTM plants
 Overall location area: 160 acres
 Permitted area: 37 acres
 Total permitted capacity: 1,710,300 yd³
 Underlying geology/soil type: Surface soils are silty clay underlain by bedrock at 100 feet below the surface

Landfilled Waste

Nature of waste: Pulp and paper mill sludge from WTM plants
 Total cumulative quantity landfilled: 1,481,515 tons
 Total cumulative volume landfilled: 1,500,000 yd³
 Liquid to solid ratio: 0.03 L/kg

Leachate Quantity

Average annual leachate generation: 8,522,600 gallons
 Average annual precipitation: 29.7 inches

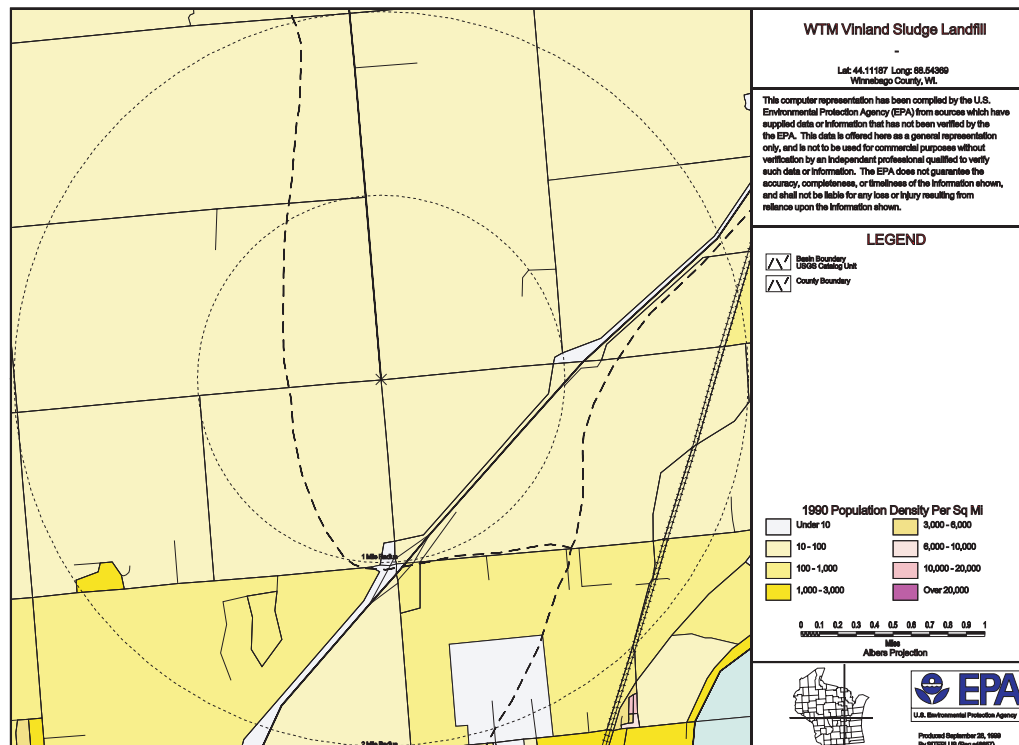


Exhibit 1. Landfill Construction and Controls

Phase	Modules	Status	Liner	Operational Period	Design Capacity (yd ³)
1	1-6	Closed	5 feet compacted clay	Feb. 1988 to April 1993	535,500
2	1-6	Closed		Aug. 1992 to June 1998	944,400

Exhibit 2. Waste Data

Wastes Type	Quantity (tons)	Volume (yd ³)	Year
Paper mill sludge	86,874	82,530	1988
	121,689	120,186	1989
	159,171	157,204	1990
	184,053	151,484	1991
	176,370	138,874	1992
	191,204	172,256	1993
	186,238	177,370	1994
	191,050	218,986	1995
	184,866	176,063	1996
	122,081	105,047	1997

Exhibit 3. Leachate Quantity Data

Year	1993	1994	1995	1996	1997
Quantity (gallons)	12,044,510	9,221,200	10,734,880	11,932,680	11,609,500

Leachate Quality

Exhibit 4. Leachate Composition Data						
PARAMETER	Concentration (ug/l)					
	OBS	10th	50th	95th	Max	% Detect
PHYSICAL/CHEMICAL PROPERTIES						
Alkalinity (mg/l as CaCO ₃)	125	250	740	4680	6000	100%
BOD (mg/l)	70	7.8	1400	9100	11000	100%
Chloride (mg/l)	122	35.1	92	969.5	1500	100%
COD (mg/l)	99	4.96	660	12000	16000	100%
Conductivity (Micromho)	123	1588	2290	6930	10051	100%
Hardness (mg/l as CaCO ₃)	125	808	1400	5720	7700	100%
Nitrate Nitrogen (mg/l)	2	0.135	0.355	0.6025	0.63	100%
Nitrite plus Nitrate (mg/l)	9	0.048	0.13	0.568	0.68	89%
Nitrogen, Ammonia (mg/l)	8	61.3	120	186.5	190	100%
Nitrogen, Kjeldahl (mg/l)	23	11.88	120	247	430	96%
pH (su)	123	6.352	6.88	7.535	7.96	100%
Sulfate (mg/l)	123	39	240	1200	1700	100%
TDS (mg/l)	3	9	45	2344.5	2600	67%
TSS (mg/l)	119	8.8	65	2240	6300	100%
TRACE ELEMENTS						
Metals						
Antimony	1	140	140	140	140	100%
Arsenic	12	12.5	22	42.7	46	92%
Barium	15	0.482	480	1560	1700	93%
Cadmium	4	0.27	1	1.185	1.2	75%
Chromium	8	0.014	19	83.25	92	88%
Copper	10	0.009	12.35	63.75	84	90%
Iron (mg/l)	121	0.19	6.2	270	310000	100%
Lead	6	0.029	14.54	52.75	57	83%
Magnesium (mg/l)	2	0	0	0	0	0%
Manganese	21	0.15	81	2900	4800	100%
Mercury	2	0	0	0	0	0%
Nickel	12	0.0424	68.5	238	260	92%
Phosphorus (mg/l)	99	0.017	0.53	1.73	110	100%
Selenium	3	0.78	3.9	20.19	22	67%
Silver	2	1.2	6	11.4	12	50%
Sodium (mg/l)	9	145.2	210	438	450	100%
Zinc	13	0.0224	31	390	390	92%
Organics						
1,1,1-Trichloroethane	1	4.4	4.4	4.4	4.4	100%
1,2,4-Trimethylbenzene	7	0.584	0.82	2.3	2.3	100%

1,3,5-Trimethylbenzene	4	0.305	0.405	0.759	0.81	100%
Benzene	3	0.676	1.1	46.91	52	100%
Benzoic Acid	2	262	590	959	1000	100%
Bis(2-ethylhexyl) Phthalate (Dehp)	1	18	18	18	18	100%
Chloroform	2	5.338	23.41	43.741	46	100%
Dichloromethane	1	21	21	21	21	100%
Di-n-butyl Phthalate	1	80	80	80	80	100%
Ethylbenzene	7	0.392	0.72	15.24	21	100%
Hexachlorobutadiene	1	0.56	0.56	0.56	0.56	100%
Isopropylbenzene	1	0.3	0.3	0.3	0.3	100%
m,p-xylene	3	0.538	0.57	1.947	2.1	100%
m-cresol	1	1000	1000	1000	1000	100%
Naphthalene	5	3.84	7.7	9.58	10	100%
N-butylbenzene	8	0.788	2.45	5.665	5.7	100%
N-propylbenzene	1	0.54	0.54	0.54	0.54	100%
o-xylene	1	0.19	0.19	0.19	0.19	100%
p-isopropyltoluene	2	0.52	1	1.54	1.6	100%
Phenolics	1	5	5	5	5	100%
sec-butylbenzene	3	1.04	1.6	2.32	2.4	100%
Styrene	4	0.758	1.15	3.285	3.6	100%
tert-butylbenzene	2	1.025	1.325	1.6625	1.7	100%
Toluene	8	1.17	8.25	262.05	380	100%

Data Source

Wisconsin Department of Natural Resources File review conducted by SAIC (September 1999)

LANDFILL CASE 6: SUPERIOR EMERALD PARK MUNICIPAL LANDFILL

Identification

Name: Superior Emerald Park Landfill
Address: W124 S10629 South 124th Street
 Muskego, WI 53150
Owner: Superior
Ownership status: Commercial
Facility contact: General Manager, 414-529-1360
State license No.: 03290
Landfill type: Municipal Solid Waste (MSW)
Permitting status: Active

Landfill Construction and Controls

Type of LCS: Standard with 1-foot drainage layer
Number of phases: Three (3)
Status: Portions of phases 2 and 3 are active
Liner type: 5 feet of compacted clay and 60 mil geomembrane
Cover type: 6 inch daily cover of shredder fluff
Operational period: November 1994 to present
Permitted to accept: Municipal, biomedical, contaminated soil, demolition, wastewater treatment (WWT) sludge, and foundry wastes from Waukesha and Milwaukee counties
Overall location area: 300 acres
Permitted area: 35 acres
Total permitted capacity: 3,550,360 yd³
Underlying geology/soil type: Silt and clay loams underlain by gravel and dolomite/shale bedrock
Special practice: Began re-circulating leachate in August of 1998.

Landfilled Waste

Nature of waste: MSW, WWT sludge, and contaminated soil
Total cumulative quantity landfilled: 2,675,780 tons (as of January 1999)
Total cumulative volume landfilled: 2,725,876 yd³ (as of January 1999)
Liquid to solid ratio: 0.004 L/kg

Leachate Quantity

Average leachate generation: 2,420,000 gallons
Average annual precipitation: 31.6 inches

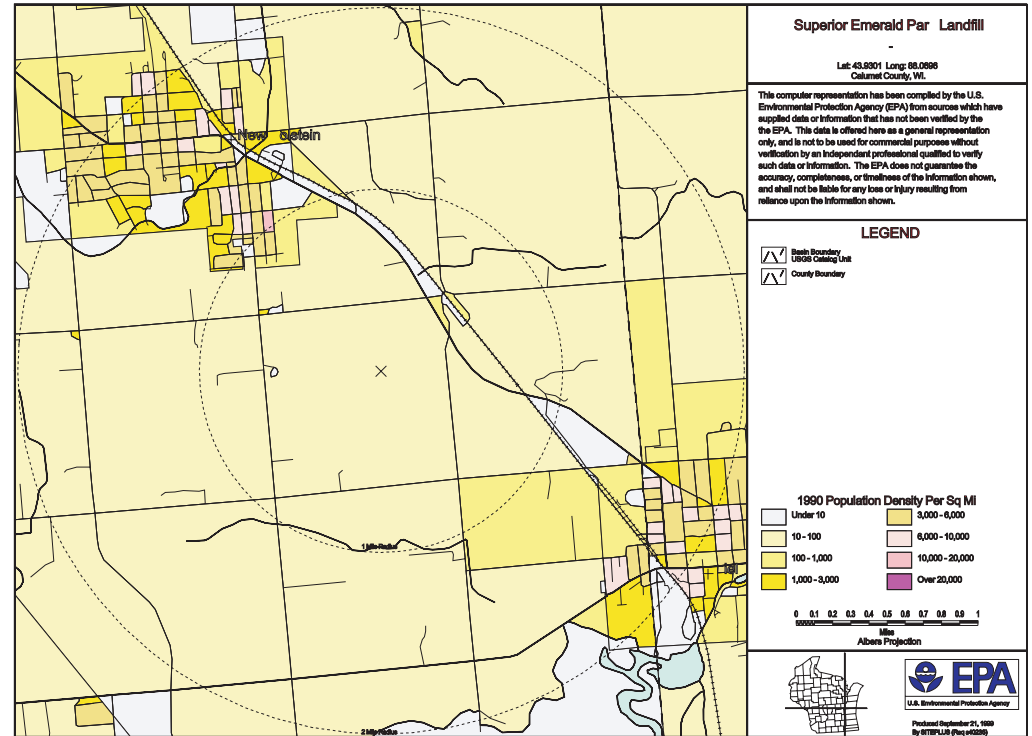


Exhibit 1. Landfill Construction and Controls				
Phase	Status	Liner	Operational Period	Final Cover
1	Closed	5 feet of compacted clay and 60 mil geomembrane	December 1994 to 1997	2 feet of clay
2	Active		1996 to present	2 feet of clay (West slopes only)
3A	Active		Mid-1997 to present	
3B	Active		Late 1998 to present	N/A

Exhibit 2. Waste Data					
Waste Type	Quantity (tons)				
	1994	1995	1996	1997	1998
MSW	11,479	122,265	318,892	431,878	430,334
Foundry	7	18,985	75,848	79,022	107,621
Wastewater treatment wastes	4,738	6,565	4,524	594	1,945
Petro contaminated soils		102,732	217,352	196,961	299,596
Demolition waste		29,350	40,765	41,539	44,003
Shredder fluff (used as daily cover)		13,671	16,675	24,012	20,222
Miscellaneous		8,150	10,346	8,863	11,221

Filling began in November of 1994
 Identified only as special waste

Exhibit 3. Leachate Quantity Data					
Year	1994	1995	1996	1997	1998
Quantity (gallons)	212,900	2,789,400	1,932,900	1,776,000	3,188,000

Leachate Quality

Exhibit 4. Leachate Composition Data						
PARAMETER	Concentration (ug/l)					
	OBS	10th	50th	95th	MAX	% Detect
PHYSICAL/CHEMICAL PROPERTIES						
Alkalinity (mg/l as CaCO ₃)	7	820	2160	3390	3600	100%
BOD (mg/l)	19	560.4	1600	3442	5440	100%
Chloride (mg/l)	7	116.8	280	707.4	750	100%
COD (mg/l)	11	660	1600	3550	3580	100%
Conductivity (Micromho)	17	1590.8	4200	5676	6460	100%
Hardness (mg/l as CaCO ₃)	6	759.5	1070	2297.5	2400	100%
Nitrogen, Ammonia (mg/l)	7	10.508	37.4	83.94	84	100%
Nitrogen, Kjeldahl (mg/l)	18	22.8	48.5	124.05	130	100%
pH (su)	18	6.197	6.705	9.255	12.4	100%
Sulfate (mg/l)	6	20	60.5	105.25	110	100%
TSS (mg/l)	19	31.2	82	236.8	280	100%
TRACE ELEMENTS						
Metals						
Arsenic	3	16.8	20	20.9	21	100%
Barium	3	442	650	866	890	100%
Boron (mg/l)	3	1.992	2.76	3.966	4.1	100%
Cadmium	3	4.7	8.3	14.33	15	100%
Chromium	5	10	11	29.8	32	100%
Copper	3	6.64	12	334.2	370	100%
Cyanide (mg/l)	6	0.11	0.1945	0.78625	0.88	100%
Iron (mg/l)	7	15.44	55	206.1	243	100%
Manganese	6	470	570	985	990	100%
Nickel	6	36	54	140	160	100%
Phosphorus (mg/l)	18	0.0585	0.155	0.4685	0.8	100%
Sodium (mg/l)	7	67.44	160	317.9	347	100%
Zinc	6	20.5	116	450	540	100%
Organics						
1,1,1-Trichloroethane	5	7.56	35	86.6	93	100%
1,1-Dichloroethane	7	7.02	21	62.8	73	100%
1,2,4-Trimethylbenzene	5	8.02	19	26	27	100%
1,2-Dichloroethane	1	2.1	2.1	2.1	2.1	100%
1,3,5-Trimethylbenzene	4	2.46	7.5	11	11	100%
Benzene	4	4.32	7.6	9.775	10	100%
Benzoic Acid	2	2560	3200	3920	4000	100%
Bis(2-ethylhexyl) Phthalate (Dehp)	1	10	10	10	10	100%
Bromomethane	2	19.98	91.1	171.11	180	100%

Chloroethane	3	16	24	25.8	26	100%
Chloroform	1	2.6	2.6	2.6	2.6	100%
Chloromethane	4	23.7	82	375	420	100%
cis-1,2-dichloroethene	4	6.74	16.5	55.4	62	100%
Dichlorodifluoromethane	5	3.26	19	101	120	100%
Dichloromethane	7	186.8	390	2850	3600	100%
Diethyl Phthalate	3	20.2	21	48.9	52	100%
Ethylbenzene	5	36.8	58	92.8	100	100%
Fluorotrichloromethane	3	12.72	50	113	120	100%
Isopropylbenzene	2	1.85	3.25	4.825	5	100%
m,p-xylene	4	46.3	73.5	108.5	110	100%
m-cresol	3	190	510	3921	4300	100%
Methyl tert-butyl Ether (mtbe)	3	16.2	33	66.3	70	100%
Naphthalene	2	5.66	5.9	6.17	6.2	100%
N-butylbenzene	1	6.3	6.3	6.3	6.3	100%
N-propylbenzene	2	2.67	3.75	4.965	5.1	100%
o-cresol	1	22	22	22	22	100%
o-xylene	3	15.4	17	36.8	39	100%
p-cresol	1	480	480	480	480	100%
p-dichlorobenzene	3	3.12	5.6	5.78	5.8	100%
Phenol	3	166	310	454	470	100%
Phenolics	5	822	1200	2014	2200	100%
p-isopropyltoluene	4	4.02	5.25	5.67	5.7	100%
Styrene	4	3.63	8.75	80.7	93	100%
Tetrachloroethylene	2	5.29	6.05	6.905	7	100%
Toluene	7	109.6	280	464	470	100%
Trichloroethene	6	4.15	8.7	27	31	100%
Vinyl Chloride	3	10.08	18	18.9	19	100%
Xylenes	2	83.2	104	127.4	130	100%

Data Source

Wisconsin Department of Natural Resources File review conducted by SAIC (September 1999)

LANDFILL CASE 7: WEPCO CALEDONIA ASH MONOFILL

Identification

Name: WEPCO Caledonia Ash Monofill
 Address: 8719 Douglas Avenue
 Caledonia, WI 53108
 Owner: Wisconsin Electric Power Company (WEPCO)
 Ownership status: Captive
 Facility contact: Timothy Muehlfeld, Project Manager, 414-221-2345
 State license no.: 03232
 Landfill type: Industrial (Combustion ash)
 Permitting status: Active

Landfill Construction and Controls

Type of LCS: Standard
 Number of phases: Eighteen (18)
 Status: Phase 8 active
 Liner type: 5 to 6 feet of compacted clay (Phases 1–4, 6 and 8)
 Cover type: 1 to 2 feet compacted clay, rooting one and topsoil (Phases 1–4 and 6)

Operational period: October 1990 to present
 Estimated year of closure: 2013 (as of 1997)
 Waste acceptance: Coal combustion ash and lightweight aggregate plant waste from WEPCO plants

Permitted area: 45 acres
 Total permitted capacity: 4,050,000 yd³
 Underlying geology/soil type: Silty clays underlain by dolomite bedrock
 Special practices: Began using leachate as dust suppressant and compression aid in September of 1993

Landfilled Waste

Nature of waste: Utility plant ash/sludge and lightweight aggregate plant waste
 Total cumulative quantity landfilled: 938,206 tons (as of January 1997)
 Total cumulative volume landfilled: 869,825 yd³ (as of January 1997)
 Liquid to solid ratio: 0.034 L/kg

Leachate Quantity

Average annual leachate generation: 8,417,471 gallons
 Average annual precipitation: 29.1 inches

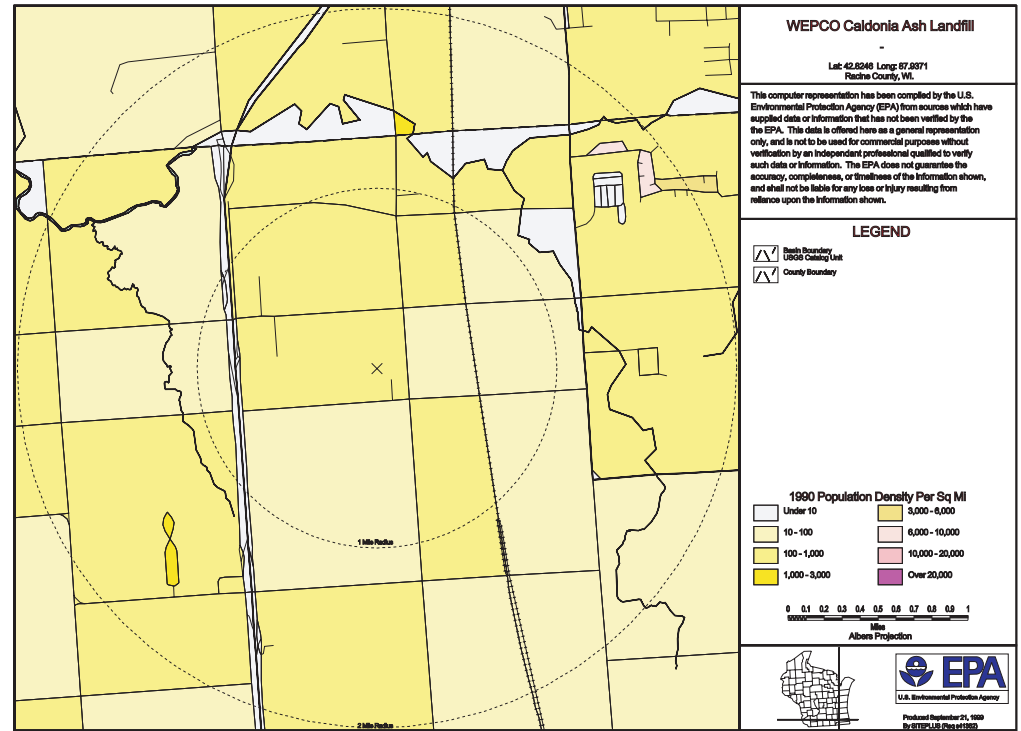


Exhibit 1. Landfill Construction and Controls

Phase	Status	Operational Period	Final Cover Installed
1	Closed	October 1990 to 1993	1994
2			
3	Closed	November 1993 to 1996	Early 1997
4	Closed	December 1994 to 1997	Mid 1998
5	Unknown		
6	Closed	February 1997 to 1998	Early 1999
7	Unknown		
8	Active	May 1999 to present	N/A
9–18	Proposed		

Exhibit 2. Waste Data

Waste Type	Quantity (tons)						
	1990	1991	1992	1993	1994	1995	1996
Combustion ash/sludge	20,000	82,335	108,421	194,419	220,334	192,578	105,189
Lightweight aggregate plant waste	—	—	—	—	79	5,715	5,136

Leachate Quality

Exhibit 3. Leachate Composition Data						
PARAMETER	Concentration (ug/l)					
	OBS	10th	50th	95th	MAX	% Detect
Physical/Chemical Properties						
Alkalinity (mg/l as CaCO ₃)	23	102	130	529	660	100%
Chloride (mg/l)	14	22.3	33	75.95	87	100%
COD (mg/l)	21	0	4	35	110	52%
Hardness (mg/l as CaCO ₃)	16	230	827	1388	1400	100%
Nitrogen, Ammonia (mg/l)	1	0.76	0.76	0.76	0.76	100%
Nitrogen, Kjeldahl (mg/l)	2	0.081	0.405	0.7695	0.81	50%
pH (su)	22	8.11	10.6	12.495	12.8	100%
Specific Conductance (umho/cm)	22	1650	2965	4352.5	4360	100%
Sulfate (mg/l)	23	414	980	2400	2400	100%
TSS (mg/l)	22	11.2	170	4877.5	7960	95%
TRACE ELEMENTS						
Metals						
Barium	2	197	225	256.5	260	100%
Boron (mg/l)	22	6.66	16	30.85	35	100%
Calcium (mg/l)	14	78.3	110	264.5	310	100%
Chromium	2	42	130	229	240	100%
Copper	2	3.5	5.5	7.75	8	100%
Iron (mg/l)	22	0.002	2.1	18.85	26	86%
Magnesium (mg/l)	12	0.004	3.5	22.85	30	83%
Molybdenum	12	1.8	2.4	6.49	7.7	100%
Potassium (mg/l)	12	42.6	68	93.5	110	100%
Selenium	22	14	25.5	79.55	810	100%
Sodium (mg/l)	12	184.4	310	430	430	100%

Data Source

Wisconsin Department of Natural Resources File review conducted by SAIC (September 1999)

LANDFILL CASE 8: IN LES MOUNTAIN C D LANDFILL

Identification

Name: Ingles Mountain C&D Landfill
Address: 3070 First Street
 Radford A 24141
Owner: New River Resource Authority (NRRA)
Ownership status: Commercial
Facility contact: Fred Hilliard, 540-674-1677
State agency contact: ate lass, Inspector, 540-562-6700
State permit no.: 526
State discharge permit: RP0100 (expired September 30, 1994)
Landfill type: Construction & Demolition Debris (C&D)
Permitting status: Inactive since 1997 and preparing for full closure (as of August 1999)

Landfill Construction and Controls

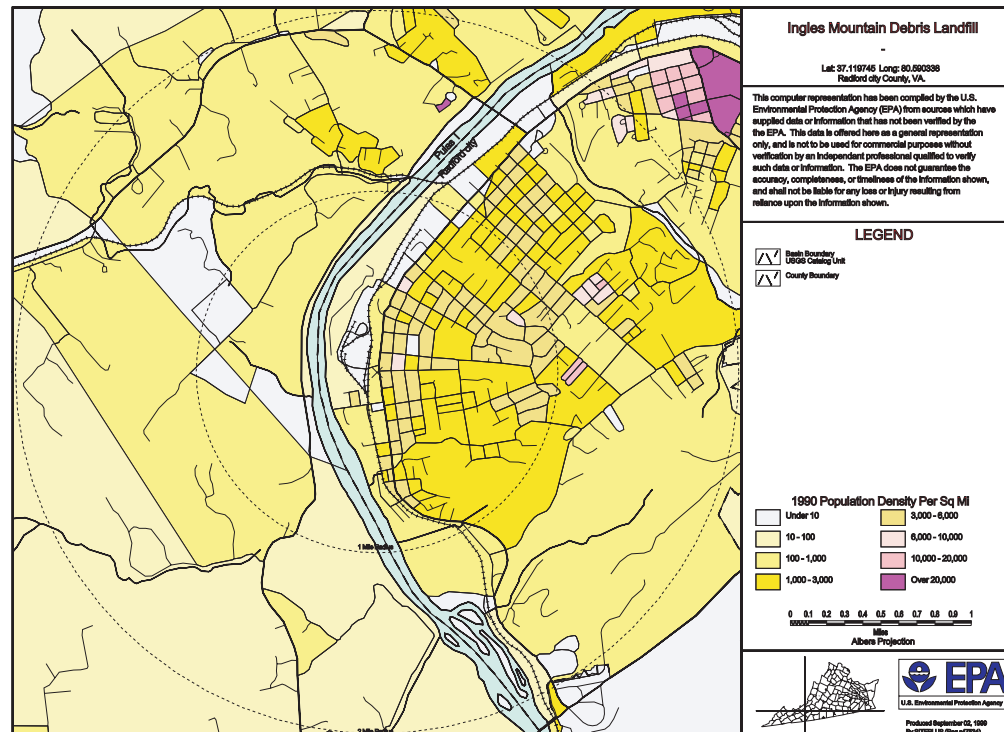
Type of LCS: French drain system in which debris and sanitary leachates are comingled
Status: Inactive (not accepting waste)
Liner type: 1 foot of compacted clay liner
Cover type: The facility has not undergone final closure but has installed a 30 mil synthetic cover
Operational period: September 1989 to May 1997
Regulatory/permitting controls: Permitted to accept only construction waste, debris waste, demolition waste, land clearing debris, tires, white goods, and bulk household items
Waste acceptance: Accepts non-hazardous debris, consisting of stumps and trees, construction and demolition debris, pallets not suitable for mulching, and appliances which cannot be recycled
Overall location area: 20 acres
Permitted area: 4.08 acres
Landfill capacity: 92,000 yd³
Landfill dimensions: 600 x 510 feet
Underlying geology/soil type: Intensely faulted and folded sedimentary rock
Depth to aquifer: 34 feet
Special practices: Debris and sanitary leachates are comingled

Landfilled Waste

Nature of waste: Household debris (50%), demolition debris (20%), miscellaneous (30%)
Average annual landfilled quantity: 6,815.2 tons
Total cumulative landfilled quantity: Approximately 67,000 tons (over two years of capacity remaining)
Liquid to solid ratio: Approximately 0.056 L/kg

Leachate Quantity

Annual quantity generated (1993): 992,100 gallons
Annual precipitation (1993): 49.11 inches



Leachate Quality

Exhibit 1. Leachate Composition					
PARAMETER	Concentration (ug/l)				
	OBS	10 th	50 th	90 th	MAX
PHYSICAL/CHEMICAL CHARACTERISTICS					
BOD	1	13000.0	13000.0	13000.0	13000.0
COD	1	305000.00	305000.00	305000.00	305000.00
TDS	1	1430000.0	1430000.0	1430000.0	1430000.0
pH	1	7.1	7.1	7.1	7.1
Ammonia	1	850.0	850.0	850.0	850.0
Nitrate/Nitrite	1	950.00	950.00	950.00	950.00
Total Phosphorus	1	120.0	120.0	120.0	120.0
Total Phenols	1	59.0	59.0	59.0	59.0
Total Sulfide	1	29000.0	29000.0	29000.0	29000.0
TRACE CONTAMINANTS					
Metals					
Arsenic	1	10.4	10.4	10.4	10.4
Barium	1	321.0	321.0	321.0	321.0
Boron	1	5780.0	5780.0	5780.0	5780.0
Cadmium	1	9.40	9.40	9.40	9.40
Calcium	1	194000.00	194000.00	194000.00	194000.00
Cerium	1	254.00	254.00	254.00	254.00
Chloride	1	104000.00	104000.00	104000.00	104000.00
Erbium	1	8.90	8.90	8.90	8.90
Europium	1	2.40	2.40	2.40	2.40
Fluoride	1	3300.00	3300.00	3300.00	3300.00
Gadolinium	1	19.70	19.70	19.70	19.70
Indium	1	94.20	94.20	94.20	94.20
Iridium	1	1000.00	1000.00	1000.00	1000.00
Iron	1	2090.00	2090.00	2090.00	2090.00
Lithium	1	15.50	15.50	15.50	15.50
Lutetium	1	4.40	4.40	4.40	4.40
Magnesium	1	67100.00	67100.00	67100.00	67100.00
Manganese	1	1280.00	1280.00	1280.00	1280.00
Mercury	1	0.33	0.33	0.33	0.33

Molybdenum	1	6.60	6.60	6.60	6.60
Neodymium	1	36.70	36.70	36.70	36.70
Niobium	1	304.00	304.00	304.00	304.00
Platinum	1	228.0	228.0	228.0	228.0
Rhenium	1	86.7	86.7	86.7	86.7
Scandium	1	2.0	2.0	2.0	2.0
Silicon	1	6300.0	6300.0	6300.0	6300.0
Sodium	1	134000.0	134000.0	134000.0	134000.0
Strontium	1	5380.0	5380.0	5380.0	5380.0
Terbium	1	131.0	131.0	131.0	131.0
Thulium	1	3.8	3.8	3.8	3.8
Uranium	1	73.6	73.6	73.6	73.6
Zirconium	1	16.9	16.9	16.9	16.9
Organics					
Pesticides					
Dalapon	1	0.31	0.31	0.31	0.31
Disulfoton	1	7.91	7.91	7.91	7.91
MCPA	1	561.00	561.00	561.00	561.00
MCPD	1	150.00	150.00	150.00	150.00
2,4,5-TP	1	0.23	0.23	0.23	0.23

Data source

Effluent Guidelines for Landfill Point Source Category: Ingles Mountain Sampling Event, October 18, 1994.

LANDFILL CASE 9: LA CROSSE COUNTY MUNICIPAL LANDFILL

Identification

Name: La Crosse County Landfill
Address: 6500 State Road 16
 La Crosse, WI 54601-1830
Owner: La Crosse County
Ownership status: Municipal
Facility contact: Brian Tippetts, SW Manager, 608-785-9572
State license no.: 03253
Landfill type: Municipal Solid Waste (MSW)
Permitting status: Active

Landfill Construction and Controls

Type of LCS: Standard
Number of phases: Six (6)
Status: Phases 1–3 are active
Liner type: 5 feet or 4 feet of compacted clay and 60 mil HDPE
Operational period: December 31, 1999 to present
Waste acceptance: Non-hazardous municipal, commercial, industrial, demolition wastes and combustion ash
Permitted area: 25.3 acres
Total permitted capacity: 1,867,400 yd³ (1,471,100 yd³ waste only)
Estimated year of closure: 2020 (estimated as of 1997)
Special practices: MSW leachate is stored with C&D leachate

Landfilled Waste

Nature of waste: Municipal, commercial, industrial, demolition wastes and ash from a resource recovery facility
Total cumulative quantity landfilled: 223,305 tons (as of Jan. 1997)
Total cumulative volume landfilled: 314,700 yd³ (as of Jan. 1997)
Liquid to solid ratio: 0.13 L/kg

Leachate Quantity

Average annual leachate generation: 4,540,000 gallons
Average annual precipitation: 30.8 inches

Exhibit 1. Landfill Construction and Controls				
Phase	Status	Liner	Operational Period	Estimated Waste Capacity (yd ³)
1	Active	5 feet of compacted clay and 60 mil HDPE geomembrane	December 1991 to present	107,650
2	Active		1993 to present	166,600
3	Active	4 feet of compacted clay and 60 mil HDPE geomembrane	Mid-1996 to present	286,000
4	Constructed		N/A	335,700
5	Proposed			363,100
6	Proposed			212,050

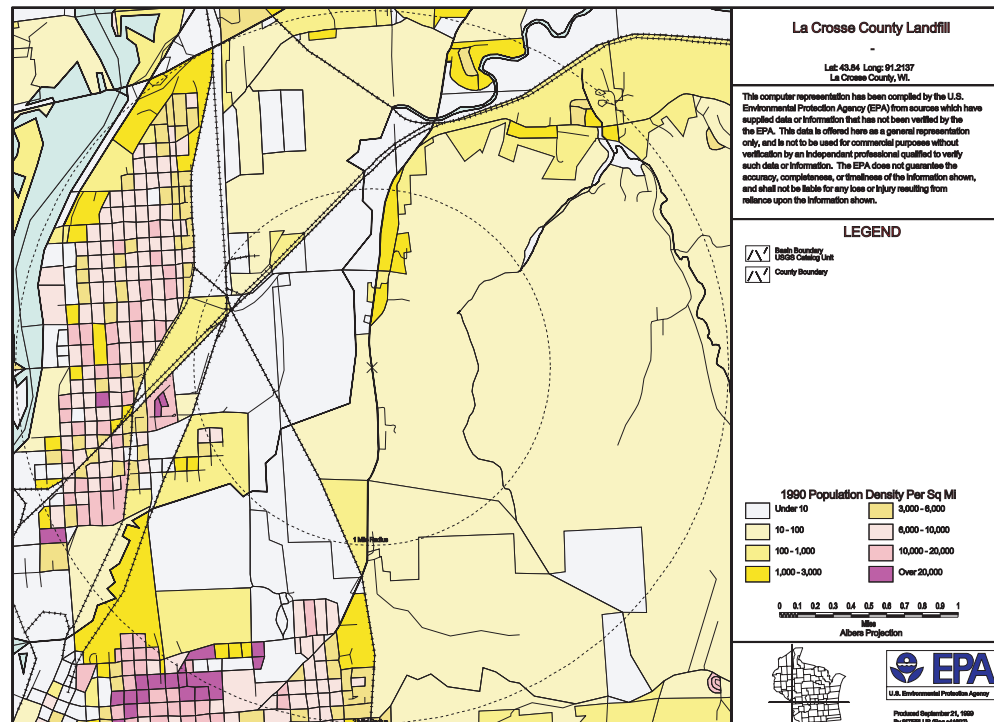


Exhibit 2. Waste Data			
Waste Type	Quantity (tons)	Volume (yd ³)	Year
MSW	135	270	1991
MSW	33,119	66,238	1992
Combustion ash/sludge	9,956	7,367	
MSW	32,256	49,884	1993
Combustion ash/sludge	9,840	7,282	
MSW	37,173	55,760	1994
Combustion ash/sludge	10,285	7,611	
MSW	35,020	52,530	1995
Combustion ash/sludge	10,151	7,613	
MSW	34,960	52,440	1996
Combustion ash/sludge	10,410	7,703	

Operations began December 31, 1991

Exhibit 3. Leachate Quantity Data							
Year	1992	1993	1994	1995	1996	1997	1998
Quantity (gallons)	4,580,000	3,050,000	3,410,000	2,860,000	5,050,000	5,380,000	7,430,000

Leachate Quality

Exhibit 4. Leachate Composition Data						
PARAMETER	Concentration (ug/l)					
	OBS	10th	50th	95th	MAX	% Detect
PHYSICAL/CHEMICAL PROPERTIES						
Alkalinity (mg/l as CaCO ₃)	57	70	1468	4112	5480	100%
Bod (mg/l)	148	2.01	118	4729.7	15467	95%
COD (mg/l)	147	111.9	984.7	6921.4	23342	100%
Hardness (mg/l as CaCO ₃)	56	419	1625	4741.3	5975	100%
pH (su)	149	6.474	7.06	7.41	7.67	100%
Specific Conductance (umho/cm)	149	3112	11450	20000	20000	99%
TDS (mg/l)	2	14.64	49.6	88.93	93.3	100%
TSS (mg/l)	146	10	30.7	294.5	1362	99%
TRACE ELEMENTS						
Metals						
Antimony	7	0	0	708.7	1000	29%
Arsenic	37	0	10	50	110	84%
Barium	6	445	630	1140	1200	100%
Boron (mg/l)	4	0.31	0.72	1.9335	2.1	100%
Cadmium	60	0	0.25	40.5	60	50%
Chromium	37	0	45	246	430	57%
Copper	37	0	0	84	460	32%
Cyanide (mg/l)	31	0	0	0	0.016	3%
Fluoride (mg/l)	37	0.54	0.88	1.728	4.58	100%
Iron (mg/l)	48	0	3.55	103.85	257.45	85%
Lead	60	0	0	230	270	25%
Manganese	14	13.2	1605	20272	47500	93%
Mercury	38	0	0	0.315	1.8	16%
Molybdenum	5	0.004	0.02	0.0368	0.041	80%
Nickel	39	0	99	862	2820	72%
Nitrogen, Ammonia (mg/l)	33	2.75	287	679.6	925	97%
Nitrogen, Kjeldahl (mg/l)	15	0.974	218	626.9	664	100%
Phosphorus (mg/l)	25	2.264	3.12	4.448	7.5	100%
Potassium (mg/l)	5	229.6	268	849.8	909	100%
Silver	7	0	0	2.66	3.8	14%
Sodium (mg/l)	48	64.31	989.2	3974	4832.15	100%
Sulfate (mg/l)	100	33.47	216.5	577.55	1140	95%
Sulfide (mg/l)	67	0	3.48	11.94	23	88%
Zinc	115	54.4	141	11220	23700	95%
Organics						
1,1,1-Trichloroethane	52	0	0	21.61	130	8%
1,1,2,2-Tetrachloroethane	44	0	0	0	22.68	2%
1,1,2-Trichloroethane	52	0	0	0	8.48	2%
1,1-Dichloroethane	52	0	0	26.26	122	33%
1,1-Dichloroethylene	44	0	0	5.3655	150.5	9%
1,2,3-Trichlorobenzene	33	0	0	2.592	96.66	6%
1,2,3-Trichloropropane	33	0	0	0	28.98	3%

1,2,4-Trichlorobenzene	36	0	0	1.42	97.78	6%
1,2,4-Trimethylbenzene	33	0	0	36.95	82.94	48%
1,2-Dichloropropane	52	0	0	0	4.22	2%
1,3,5-Trimethylbenzene	33	0	1.5	39.752	88.65	61%
1,3-Dichloropropane	33	0	0	0	14.34	3%
2,2-Dichloropropane	33	0	0	0	4.78	3%
Benzene	52	0	0	4.97	5.96	33%
Bromobenzene	33	0	0	16.32	32.59	39%
Bromomethane	52	0	0	52.36	160	21%
Butylbenzene, N-	33	0	0	11.466	95.52	18%
Butylbenzene, sec-	33	0	0	4.868	39.23	18%
Butylbenzene, tert-	33	0	0	4.394	47.15	21%
Chloride (mg/l)	58	237.3	2193	11192	12566	100%
Chlorobenzene	52	0	0	0.6345	3.27	6%
Chloroethane	52	0	0	0	3.98	4%
Chloromethane	52	0	0	13.197	48	10%
cis-1,2-dichloroethene	44	0	0	2.5145	18.22	9%
cis-1,3-dichloropropene	49	0	0	2.384	12	14%
Dibromochloromethane	52	0	0	0	27.13	2%
Dichlorodifluoromethane	43	0	0	41.04	97.4	40%
Dichloromethane	47	0	0	75.53	144.7	15%
Ethylbenzene	52	0	3.99	35.14	72	65%
Fluorotrichloromethane	52	0	0	18.9	56	6%
Hexachlorobutadiene	36	0	0	3.525	63.42	6%
Isopropylbenzene	33	0	0	3.158	10.3	15%
m-dichlorobenzene	54	0	0	0	36.86	2%
Naphthalene	35	0	3.07	36.075	57.05	57%
n-propylbenzene	33	0	0	17.214	44.73	27%
o-chlorotoluene	33	0	0	0.61	2.39	9%
o-dichlorobenzene	54	0	0	3.317	44.32	9%
p-chlorotoluene	33	0	0	15.858	42.69	18%
p-dichlorobenzene	54	0	0.645	36.577	55.03	52%
Phenolics	6	41.95	319.5	629.5	696	100%
p-isopropyltoluene	33	0	0	9.436	62.11	39%
Styrene	33	0	0	29.58	65.09	15%
Tetrachloroethylene	49	0	0	150.28	676	10%
Toluene	52	0	18.13	445.6	523.5	73%
trans-1,2-dichloroethene	42	0	0	0	0.35	2%
trans-1,3-dichloropropene	49	0	0	4.198	17.39	8%
Tribromomethane	52	0	0	0	1.4	2%
Trichloroethylene (TCE)	45	0	0	18.134	30	31%
Vinyl Chloride	52	0	0	33.869	52.5	27%
Xylenes	52	0	12.8	137.63	300	71%

Data Source

Wisconsin Department of Natural Resources File review conducted by SAIC (September 1999)

REENTREE MUNICIPAL LANDFILL

Identification

Name:	Superior reentree Landfill Inc.
Address:	635 Toby Rd. ersey, PA 15846
Owner:	Browning-Ferris Industries
Ownership status:	Commercial
Facility contact:	Thaddeus Sorg, Site Manager, 814-265-1744
EPA ID:	PAD987374535
NPDES ID:	PA0103446
Landfill type:	Subtitle D
Permitting status:	Active

Landfill Construction and Controls

Type of LCS:	Standard double leachate collection system
Number of cells:	Fifteen (15)
Status:	11 cells are active and 4 cells are closed (as of January 1994)
Liner type:	Double synthetic liner (60 mil) with 3 feet of clay or single synthetic liner

Operational period:	September 1986 to present
Waste acceptance:	Accepts non-hazardous industrial wastes (residual wastes), municipal solid wastes (MSW), industrial wastewater treatment plant sludges, municipal treatment plant sludges, construction and demolition debris, asbestos, and incinerator ash. No yard waste.

Overall location area: 1,336 acres
Total permitted area: 91 acres
Special practices: Sludge is dried and placed in a rolloff container and disposed of in the reentree Landfill. Annual dewatered sludge landfilled: 125 tons

Landfilled Waste

Nature of waste:	MSW (60%) and residual/industrial (40%)
Average annual landfilled quantity:	320,000 tons
Total cumulative landfilled quantity:	Approximately 2,500,000 tons (as of January 1994)
Liquid to solid ratio:	0.014 L/kg (as of January 1994)

Leachate Quantity

Average annual leachate generation:	9,700,000 gallons
Average annual precipitation:	43 inches

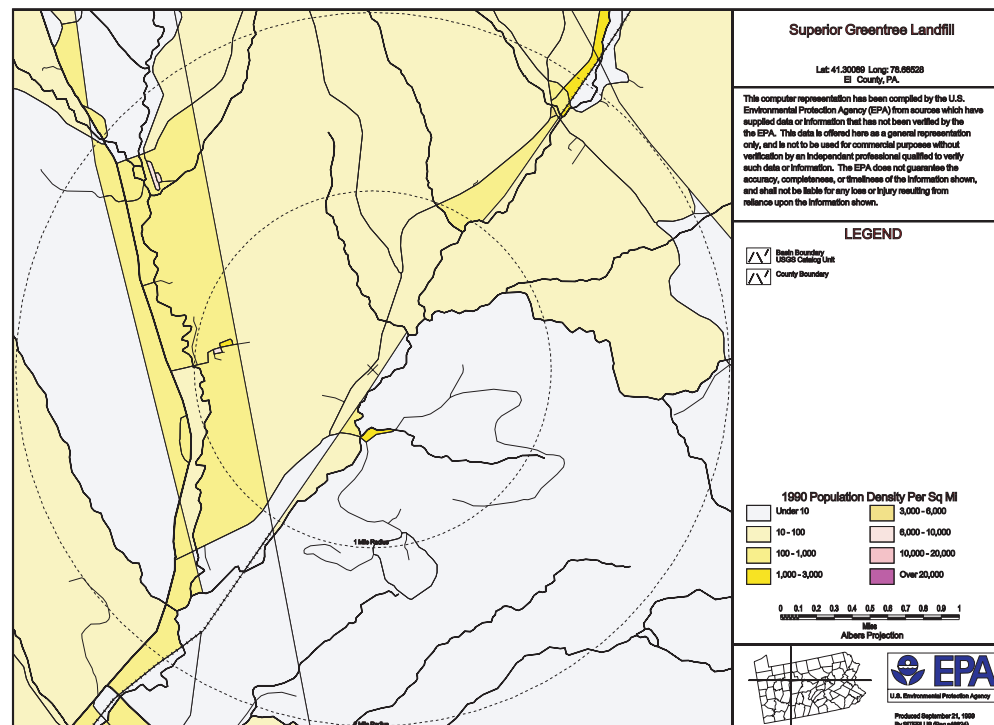


Exhibit 1. Landfill Construction and Controls			
Phase	Cell(s)	Status	Liner
A	1-4	Closed	Single 60 mil synthetic liner with 3 feet of clay
	5	Active	Double 60 mil synthetic liner with 3 feet of clay
B	1-3		
C	1		
D	1		
E	1-5		

Exhibit 2. Leachate Quantity Data						
Year	1994	1995	1996	1997	1998	1999
Quantity (gallons)	11,169,582	9,543,541	12,214,560	8,989,795	6,652,559	4,742,044

quantity for January through March only.

Leachate Quality

Exhibit 3. Leachate Composition Data					
PARAMETER	Concentration (ug/l)				
	OBS	10 th	50 th	90 th	MAX
Amenable Cyanide	1	13	13.00	13	13
BOD	29	698	151000.00	916400	1680000
COD	32	1458	852000.00	223300	4470000
TDS	32	3701	2972000.00	4730400	7050000
pH (su)	32	6.701	7.10	7.691	8
Nitrate/Nitrite	21	0.44	1.60	300	400
Total Cyanide	7	8.4	12.00	22.4	26
Total Nitrogen	17	4240	26900.00	181840	225000
Total Phenols	31	23	310.00	1370	1600
Total Phosphorus	9	0.02	0.06	0.264	1
TOC	32	928.5	217000.00	638400	1390000
TSS	29	86.4	54000.00	179600	254000
TRACE ELEMENTS					
Metals					
Aluminum	28	89.47	204.00	570.6	1610
Antimony	15	4.9	11.50	22.7	38
Arsenic	28	10.57	18.00	43.07	51
Barium	32	630.5	1190.00	2423	3400
Beryllium	2	0.21	0.25	0.29	0.3
Boron	31	1600	3590.00	8100	19500
Bromide	15	1300	8600.00	12840	19300
Cadmium	10	0.76	2.85	14.29	16
Calcium	14	182000	216500.00	477700	495000
Cerium	1	878	878.00	878	878
Chloride	32	630	533500.00	1135000	1610000
Chlorine	4	53	80.00	212	260
Chromium	30	17.92	25.45	53	70
Chromium (VI)	11	0.015	0.03	5.5	15
Cobalt	7	7.06	13.10	60	60
Copper	15	4.4	12.10	31.2	40
Europium	1	7.58	7.58	7.58	7.58
Flourene	1	29	29.00	29	29
Fluoride	29	0.316	240.00	400	490
Gold	3	211	211.00	219	221
Holmium	1	93.8	93.80	93.8	93.8
Iron	32	15520	29750.00	176800	242000
Iron Dissolved	17	1240	3200.00	24900	193000
Lead	13	3	6.00	9.88	17
Lithium	8	109.2	125.00	147.3	162
Magnesium	32	126200	174000.00	213800	231000
Manganese	32	2732	13000.00	28310	38300
Mercury	5	0.314	0.35	0.498	0.59
Molybdenum	6	15.85	64.60	90	100
Nickel	32	91	153.50	315	400
Niobium	1	198	198.00	198	198
Phosphorus	18	41	425.00	1130	1300
Potassium	14	137200	2475000.00	3140000	3260000
Ruthenium	1	283	283.00	283	283
Scandium	1	5.73	5.73	5.73	5.73
Selenium	4	9.04	16.90	20.77	21.1

Silicon	11	464	541.00	870	6840
Silver	6	0.45	3.50	17.95	32
Sodium	14	474400	527500.00	630500	665000
Strontium	11	1280	1830.00	3330	3370
Sulfate	20	39740	147000.00	244800	310000
Sulfide	7	285	1550.00	10200	13600
Sulfite	10	2000	5350.00	53750	87500
Sulfur	11	15200	17200.00	103000	108000
Tantalum	1	121	121.00	121	121
Thallium	10	2	12.05	16.81	17.8
Tin	4	18.84	41.20	102.06	123
Titanium	8	3.5	17.25	26.88	33.6
Vanadium	11	7	10.50	160	160
Yttrium	6	3.25	3.45	5.05	6.2
Zinc	31	37.3	104.00	180	740
Organics					
Acenaphthene	1	8.6	8.60	8.6	8.6
Acetophenone	9	11.4054	25.68	37.5682	59.441
Acetone	16	167.5	695.00	2500	3300
Aldrin	1	0.84	0.84	0.84	0.84
Alpha BHC	1	1.4	1.40	1.4	1.4
Alpha-Terpinol	9	80.739	122.31	148.7012	168.022
Ammonia as Nitrogen	11	149	182.00	201	203
Benzene	7	4	6.00	8.42	8.9
Benzo Perylene	1	17	17.00	17	17
Benzoic Acid	11	1822.63	8181.08	15882.6173	21558.09
Benzyl Alcohol	1	20.919	20.92	20.919	20.919
Bis(2-Ethylhexyl)Ether	5	0.76	4.00	4.8	5
Bis(2-Ethylhexyl)Phthalate	3	2.48	4.40	38.48	47
Butyl benzyle phthalate	1	0.41	0.41	0.41	0.41
Chlorobenzene	5	1.04	2.00	2	2
Chloroethane	3	3	7.00	51.8	63
Chrysene	1	15	15.00	15	15
Dichlorodiflouromethane	1	1	1.00	1	1
Diethyl ether	8	56.5818	63.63	143.36868	156.6446
Diethyl phthalate	10	7.27	24.00	55.7623	190
Dimethoate	1	3.5	3.50	3.5	3.5
Dimethyl Phthalate	1	10	10.00	10	10
Dimethyl sulfone	1	27.0762	27.08	27.0762	27.0762
Di-n-Butyl Phthalate	1	58	58.00	58	58
Endosulfan	1	81.5	81.50	81.5	81.5
Endosulfan Sulfate	2	0.656	3.12	5.584	6.2
Endrin	1	0.1	0.10	0.1	0.1
Ethylbenzene	19	21.8	33.00	44.2	47
Gamma BHC	4	0.15	0.15	0.15	0.15
Heptachlor	1	0.052	0.05	0.052	0.052
Hexane extractable material	11	7	12.00	16	18
Hexanoic acid	11	4578.86	16695.42	61054.68	69055.55
Isophorone	10	14.6606	16.77	20.81519	25.3979
m -xylene	1	31.8684	31.87	31.8684	31.8684
MCPA	2	435.3	468.50	501.7	510
MCPP	1	158	158.00	158	158
Methylene chloride	19	8	34.05	728	1800
N-Dodecane	1	15.103	15.10	15.103	15.103

N,N-Dimethylformadine	2	71.5665	85.60	99.6265	103.134
Naphthalene		3.68	35.30	63	63
o & p-xylene	1	15.4406	15.44	15.4406	15.4406
o-Cresol	2	41.7831	152.26	262.7439	290.364
p-Cresol	13	23.6	490.00	2320	16065
p-Cymene	1	10.138	10.14	10.138	10.138
p-Dimethylaminoazobenzene	1	38.389	38.39	38.389	38.389
Phenanthrene	1	36	36.00	36	36
Phenol	21	12.251	56.00	675.8818	850.92
Styrene	1	24.39	24.39	24.39	24.39
Tetrachloroethylene	3	1.3	2.90	13.38	16
Tetrahydrofuran	13	309	735.00	2440	3500
Toluene	27	32.7304	100.00	462	3398.9908
Trans-1,2-Dichloroethane	3	14.08564	14.63	15.271	15.431
Trichloroethylene	2	5.73	7.05	8.37	8.7
Tripropyleneglycol methyl ether	1	1136.44	1136.44	1136.44	1136.44
Vinyl chloride	5	1.72	10.43	12.93956	14.2326
Xylene	21	21	97.00	140	160
1-Propanol	6	603.5	2350.00	4500	5600
1,1-Dichloroethane	9	2.8	14.00	21.11446	21.5723
1,2-Dibromo-3-chloropropane	2	0.204	0.22	0.236	0.24
1,2-Dichlorobenzene	2	0.71	0.75	0.79	0.8
1,2-Diphenylhydrazine	1	1.7	1.70	1.7	1.7
1,4-Dichlorobenzene	7	4.4	4.40	8.64	9
1,4-Dioxane	10	162.3623	214.73	367.2307	385.3
2-Butanone	31	365	4000.00	17581.4	818746.5
2-Hexanone	9	62.7224	126.22	172.676	220
2-Picoline	1	107.329	107.33	107.329	107.329
2-Propanol	9	6.6	2400.00	5600	14000
2-Propanone	11	2594.37	7274.82	11367.89	83857.9408
2-Propenal	1	78.31	78.31	78.31	78.31
2,4-D	3	1.88	2.20	4.28	4.8
2,4-Dimethylphenol	3	13.6	28.00	32.8	34
4-Methyl-2-pentanone	27	38.1	185.00	631.0493	1000
4,4-DDT	2	0.0214	0.03	0.0326	0.034

Data Source

Effluent Guidelines for Landfill Point Source

Category: Greentree Site Visit Report, September 28, 1994.

LANDFILL CASE 11: MARATHON COUNTY AREA B MUNICIPAL LANDFILL

Identification

Name: Marathon County Area B Landfill
 Address: R18500-B Ringle Avenue
 Ringle, WI 54471-9762
 Owner: Marathon County
 Ownership status: Municipal
 Facility contact: Jim Pellitteri, Solid Waste Manager, 715-446-3339
 State license no.: 03338
 Landfill type: Municipal Solid Waste (MSW)
 Permitting status: Active

Landfill Construction and Controls

Type of LCS: Standard
 Number of phases: Three (3)
 Status: Phases 1 and 2 are active
 Liner type: 4 feet of compacted clay, 60 mil HDPE liner, and geotextile
 Estimated year of closure: 2005
 Operational period: November 1993 to present
 Waste acceptance: Municipal and commercial solid waste, sludge, foundry wastes, demolition wastes, and paper mill ash
 Overall location area: 532 acres
 Permitted area: Approximately 25 acres
 Total permitted capacity: 1,427,000 yd³
 Underlying geology/soil type: Loamy soils underlain by granite bedrock
 Depth to aquifer: 70 feet

Landfilled Waste

Nature of waste: MSW, commercial, sludges, foundry, demolition, and ash (from Weyerhaeuser Co.)
 Total cumulative quantity landfilled: 630,086 tons (as of January 1999)
 Total cumulative volume landfilled: 1,031,530 yd³ (as of January 1999)
 Liquid to solid ratio: 0.042 L/kg

Leachate Quantity

Average annual leachate generation: 5,104,300 gallons
 Average annual precipitation: 30 inches

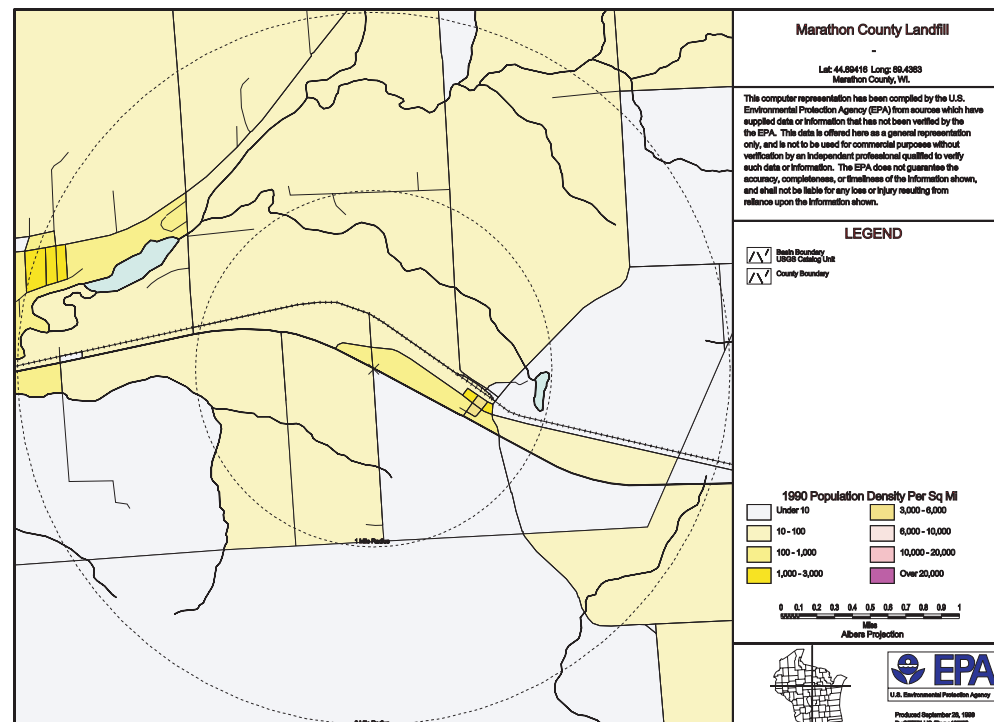


Exhibit 1. Landfill Construction and Controls

Phase	Status	Liner	Operational Period	Design Area (acres)
1A	Active	4 feet of compacted clay, 60 mil HDPE liner, and geotextile	November 1993 to present	7.25
1B	Active		February 1995 to present	2.8
2	Active		December 1996 to present	7.5
3	Proposed			6.7-7.8

Exhibit 2. Waste Data

Waste Type	Quantity (tons)					
	1993	1994	1995	1996	1997	1998
MSW and commercial	7,079	88,831	80,523	91,023	93,537	89,972
Sludges	11,183	17,591	19,139	19,370	20,600	18,601
Foundry sand	85	1,943	2,456	112	0	0
Demolition	139	15,164	12,616	12,505	15,694	13,029
Ash	173	3,084	3,557	3,755	3,734	3,590

Exhibit 3. Leachate Quantity Data

Year	1994	1995	1996	1997	1998
Volume (gallons)	2,499,913	4,498,375	4,934,779	6,249,000	7,339,642

Leachate Quality

Exhibit 4. Leachate Composition Data						
PARAMETER	Concentration (ug/l)					
	OBS	10th	50th	95th	MAX	% Detect
PHYSICAL/CHEMICAL PROPERTIES						
Alkalinity (mg/l as CaCO ₃)	14	739	2050	5570	7000	100%
BOD (mg/l)	22	72.2	475	2275	6200	100%
Chloride (mg/l)	14	158	500	1535	1600	100%
COD (mg/l)	14	437	1100	11700	13000	100%
Hardness (mg/l as CaCO ₃)	14	334	1250	3810	4200	100%
Nitrogen, Ammonia (mg/l)	12	51.1	89	241	340	100%
Nitrogen, Kjeldahl (mg/l)	1	110	110	110	110	100%
pH (su)	22	6.4	6.64	7.195	7.3	100%
Specific Conductance (umho/cm)	22	699	3500	7600	7700	100%
Sulfate (mg/l)	14	64.6	110	1730	4200	100%
TSS (mg/l)	22	19.2	185	19550	35000	100%
TRACE ELEMENTS						
Metals						
Antimony	3	0	0	21.6	24	33%
Arsenic	3	8.6	43	184.3	200	67%
Barium	3	752	2000	5690	6100	100%
Beryllium	3	10	14	50.9	55	100%
Boron (mg/l)	12	0.246	2.05	4.2	4.2	92%
Cadmium	14	0	0	106.35	120	43%
Chromium	3	23	71	214.1	230	100%
Cobalt	3	36	180	396	420	67%
Copper	3	15.2	24	434.4	480	100%
Fluoride (mg/l)	3	0.0596	0.17	0.863	0.94	100%
Iron (mg/l)	14	9.11	69.5	645.5	730	100%
Lead	14	0	0	289	510	29%
Manganese	14	1358	5250	38350	39000	93%
Mercury	14	0	0	1.985	2.7	29%
Nickel	3	8	40	292	320	67%
Phosphorus (mg/l)	11	0.56	2	35.5	58	100%
Selenium	14	0	0	42.01	110	14%
Sodium (mg/l)	14	82.2	355	628	680	100%
Thallium	3	168	840	1344	1400	67%
Vanadium	3	202	690	1599	1700	100%
Zinc	3	42	110	1181	1300	100%
Organics						
1,1,1-Trichloroethane	14	0	0	27.5	34	29%
1,1-Dichloroethane	14	0.84	13	54.75	71	86%
1,2,4-Trimethylbenzene	4	1.53	5.3	8.645	9.2	75%
1,2-Dichloroethane	14	0	0	0.168	0.48	7%
1,3,5-Trimethylbenzene	4	0	0	3.06	3.6	25%
2-Hexanone	12	0	1.5	639	1200	50%
4-Methyl-2-pentanone(MIBK)	12	7.83	70	252	340	100%

Acetone	12	142	760	6050	11000	100%
Benzene	14	0	3.2	5.35	6	64%
Benzoic Acid	3	0	0	1800	2000	33%
Bis(2-ethylhexyl)Phthalate (DEHP)	5	0	0	39	45	40%
Bromochloromethane	14	0	0	0.168	0.48	7%
Carbon Disulfide	12	0	0	15.345	22	33%
Chlorobenzene	14	0	0	1.085	3.1	7%
Chloroethane	14	0	0	11.405	22	14%
Chloroform	14	0	0	2.08	2.6	21%
cis-1,2-dichloroethene	14	0	0.5	25	38	50%
Dichlorodifluoromethane	11	0	0	3.3	4.8	18%
Dichloromethane	14	0	14.5	178	230	79%
Diethyl Phthalate	5	0	0	82.6	100	40%
Di-n-butyl Phthalate	5	0	0	31.2	39	20%
Ethylbenzene	14	4.7	24	46.25	56	100%
Fluorotrichloromethane	14	0	0	1.745	2.2	14%
Isophorone	5	0	0	43.2	54	20%
Isopropylbenzene	4	0	0	3.145	3.7	25%
m,p-xylene	14	14.45	71.5	150	150	100%
m-cresol (3-methylphenol)	3	852	2100	2460	2500	100%
Methyl Ethyl Ketone (MEK)	12	88.6	825	9290	16000	100%
Methyl Tert-butyl Ether (MTBE)	10	0	0	1.334	2	20%
n-propylbenzene	4	0	0	1.445	1.7	25%
o-cresol (2-methylphenol)	5	0	0	23.6	26	40%
o-xylene	14	4.77	25	44.7	46	100%
p-chloro-m-cresol	5	0	0	113.9	140	40%
p-cresol	2	206.1	914.5	1711.45	1800	100%
p-dichlorobenzene	14	0	0	5.29	6.2	36%
Phenol	5	20.8	130	918	1100	80%
Phenolics	1	1800	1800	1800	1800	100%
p-isopropyltoluene	4	6.18	9.7	24.45	27	100%
Tetrachloroethylene	14	0	0	3.99	4.9	29%
Tetrahydrofuran	12	275	625	923	1000	100%
Toluene	14	50.2	345	1012.5	1500	100%
Trichloroethylene (TCE)	14	0	0	8.66	9.7	36%
Vinyl Chloride	14	0	0	8.465	11	21%

Data Source

Wisconsin Department of Natural Resources File review conducted by SAIC (September 1999)

LANDFILL CASE 12: MEAD PAPER MILL MONOFILL

Identification

Name: Mead Paper Monofill
 Address: 401 South Paint Street
 Chillicothe, OH 45601
 Owner: Mead Paper
 Ownership status: Captive
 Facility contact: Elden Fink,
 Environmental Manager,
 740-772-3111 ext. 3475
 State agency contact: Steve Ryan, Ohio EPA
 (Southeast District Office)
 740-385-8501
 EPA ID: OHD043730209
 NPDES ID: OH0104507
 Landfill type: Industrial (Pulp and paper sludge)
 Permitting status: Closed (February 1993)

Landfill Construction and Controls

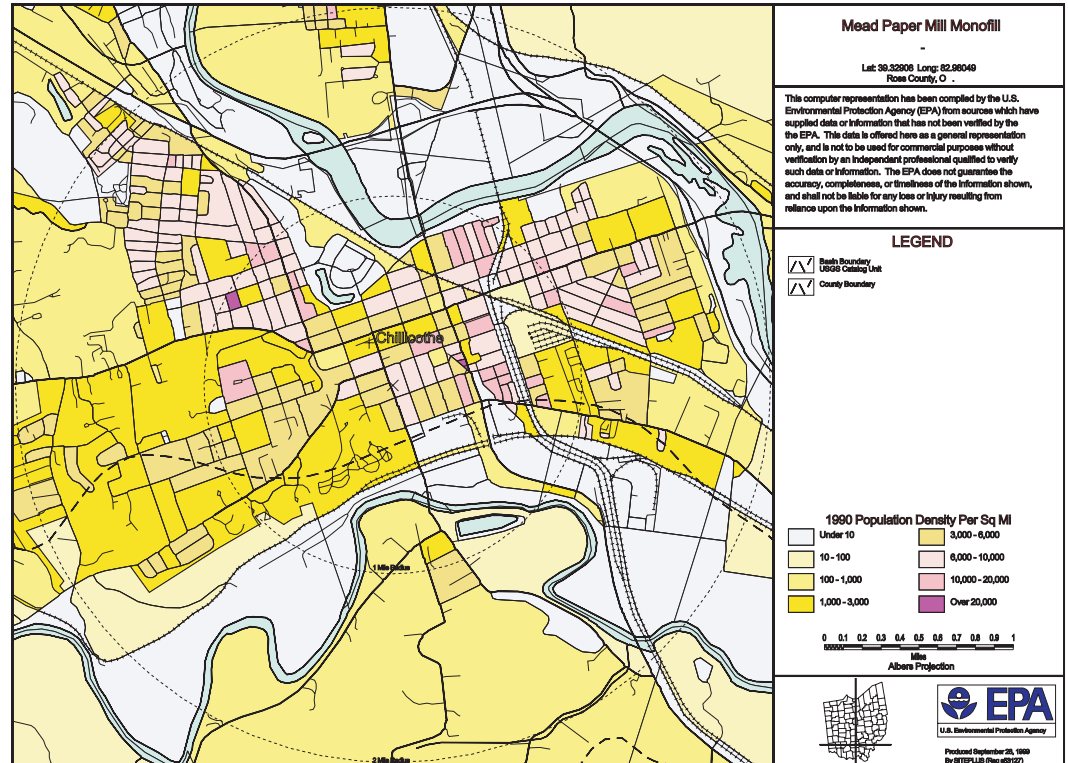
Type of LCS: Leachate is collected in two gravity flow sumps and stored
 Number of cells: One (1)
 Status: Closed
 Final cover type: Geonet and 20 mil P C overlain by 18 inches of soil and 6 inches of top soil
 Operational period: 1974 to 1990 (16 years)
 Waste acceptance: Accepted pulp sludge (mixture of clay, lime, and cellulose), fly ash and bark from Mead's Chillicothe mill
 Special practices: During LF's operation, leachate used in spray fields at the landfill in 1990, leachate was collected and treated, leachate was sprayed back onto the landfill during heavy rains in 1993, leachate spraying ceased completely

Landfilled Waste

Nature of waste: Pulp sludge thickened with bark and fly ash
 Average annual quantity landfilled: 300,000 wet tons of sludge
 Total cumulative quantity landfilled: Approximately 4,200,000 tons
 Liquid to solid ratio: Approximately 0.006 L/kg

Leachate Quantity

Average annual leachate generation: Approximately 8,200,000 gallons
 Average annual precipitation: 38.4 inches



Leachate Quality

Exhibit 1. Leachate Composition Data					
PARAMETER	Concentration (ug/l)				
	OBS	10 th	50 th	90 th	MAX
PHYSICAL/CHEMICAL PROPERTIES					
BOD	1	120	120	120	120
COD	1	1420	1420	1420	1420
TDS	1	5790	5790	5790	5790
pH	1	7	7	7	7
Nitrate/Nitrite	1	0.69	0.69	0.69	0.69
Total Phenols	1	0.52	0.52	0.52	0.52
Total Phosphorus	1	4.53	4.53	4.53	4.53
Total Recoverable Oil & Grease	1	9.47	9.47	9.47	9.47
Total Sulfide (Iodometric)	1	25.8	25.8	25.8	25.8
TOC	1	500	500	500	500
TSS	1	104	104	104	104
TRACE ELEMENTS					
Metals					
Aluminum	1	405	405	405	405
Arsenic	1	53.8	53.8	53.8	53.8
Barium	1	2050	2050	2050	2050
Bismuth	1	127	127	127	127
Boron	1	736	736	736	736
Calcium	1	599000	599000	599000	599000
Chloride	1	952	952	952	952
Chromium +6	1	0.01	0.01	0.01	0.01
Cobalt	1	27.9	27.9	27.9	27.9
Fluoride	1	0.4	0.4	0.4	0.4
Iron	1	13800	13800	13800	13800
Lithium	1	754	754	754	754
Magnesium	1	388000	388000	388000	388000
Manganese	1	7090	7090	7090	7090
Nickel	1	35.3	35.3	35.3	35.3
Phosphorus	1	4670	4670	4670	4670

Potassium	1	386000	386000	386000	386000
Silicon	1	13100	13100	13100	13100
Sodium	1	495000	495000	495000	495000
Strontium	1	3850	3850	3850	3850
Sulfur	1	19200	19200	19200	19200
Titanium	1	10.9	10.9	10.9	10.9
Zinc	1	28.3	28.3	28.3	28.3
Organics					
Ammonia as Nitrogen	1	53.2	53.2	53.2	53.2
Dicamba	1	0.41	0.41	0.41	0.41
Dichlorprop	1	7.09	7.09	7.09	7.09
Dinoseb	1	4.88	4.88	4.88	4.88
MCPA	1	551	551	551	551
p-Cymene	1	35.3	35.3	35.3	35.3
Picloram	1	1.97	1.97	1.97	1.97
Toluene	1	12.992	12.992	12.992	12.992
2-Propanone	1	167.781	167.781	167.781	167.781
2,4-D	1	3.15	3.15	3.15	3.15
2,4-DB	1	9.48	9.48	9.48	9.48
2,4,5-T	1	1.64	1.64	1.64	1.64
2,4,5-TP	1	1.26	1.26	1.26	1.26

Data source

Effluent Guidelines for Landfill Point Source Category: Mead Pre-Sampling Event, February 4, 1994.

LANDFILL CASE 13: MORMON HOLLOW ROAD C D LANDFILL

Identification

Name: Mormon Hollow Road Demolition Landfill
Address: Mormon Hollow Road
P.O. Box 202
Wendell, MA 01379
Owner: DB Enterprises, Inc.
Ownership status: Commercial
Facility contact: Dean Bennett, President, 978-544-8006
Don Adams, Delta Engineers, 607-724-1367 ext. 20
State agency contact: Mark Haley, MA DEP, 413-755-2253
State permit no.: DL0319003
Landfill type: Construction and Demolition Debris (C&D)
Permitting status: Active

Landfill Construction and Controls

Type of LCS: Primary (top liner) and secondary (bottom liner) LCS
Number of cells: Five (5)
Status: Active
Liner type: Double-lined with two layers of chlorosulfonated polyethylene (hypalon) with 18 inches of gravel between each layer
Operational period: June 1990 to present
Regulatory permitting controls: Permitted to accept non-hazardous construction and demolition debris
Waste acceptance: Does not accept glass, metal containers, plastic buckets, yard waste, leaves, lead-acid batteries, white goods, whole tires, clean unpainted wood
Overall location area: 20 acres
Permitted area: 8 acres
Landfill dimensions: 130 feet (deep), 720 feet (long), 500 feet (wide)
Permitted capacity: 99 tons (268 yd³) per day
Underlying geology/soil type: Bedrock overlain by 6 feet of compacted clay

Landfilled Waste

Nature of waste: C&D debris (consisting of waste building materials) and limited quantities of state regulated non-hazardous waste (i.e. soils contaminated with virgin petroleum products)
Quantity landfilled (1993): 36,400 tons
Cumulative landfilled quantity: 129,255 tons (as of March 1999)
Cumulative landfilled volume: 350,259 yd³ (as of March 1999)
Liquid to solid ratio: 0.013 L/kg

Leachate Quantity

Average annual quantity generated: Approximately 450,000 gallons
Average annual precipitation: 44.4 inches

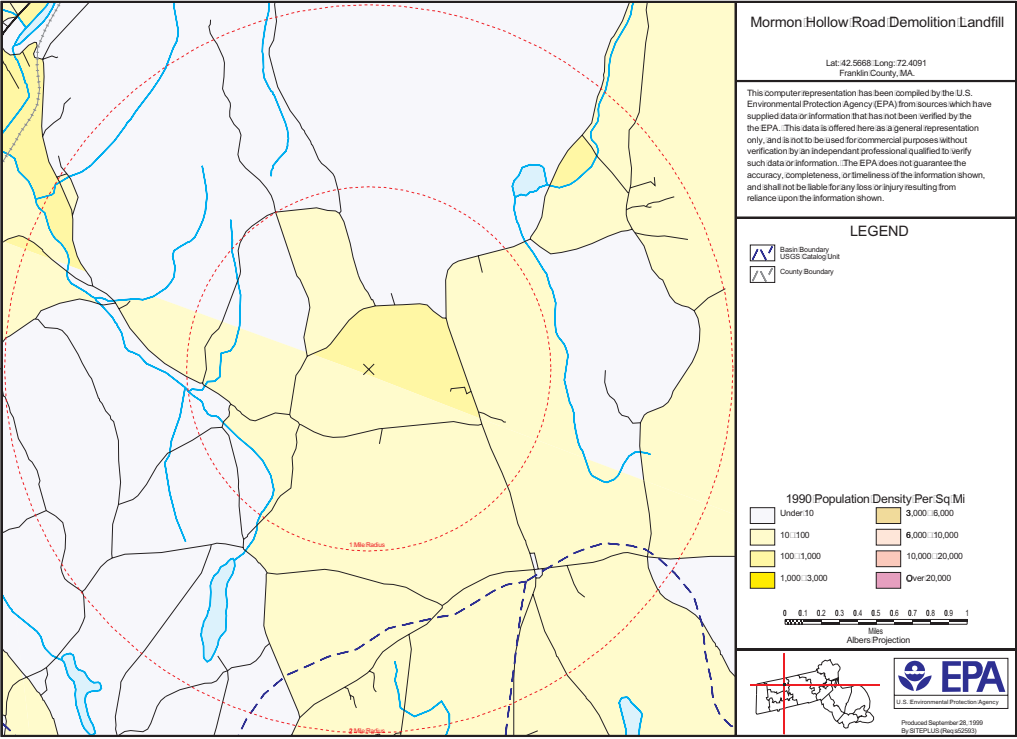


Exhibit 1. Landfill Construction and Controls		
Cell(s)	Status	Cover
1	Closed (full)	Final cover of hypalon underlying 18 inches silty sand and clay
2	Closed (full)	Intermediate cover of 12 inches of soil
3	Closed (full)	Intermediate cover of 12 inches of soil
4	Closed (full)	Intermediate cover of 12 inches of soil
5	Subsection 5a – Active	N/A
	Subsection 5b – not prepared to receive waste	N/A
	Subsection 5c – not prepared to receive waste	N/A

Leachate Quality

Exhibit 2. Leachate Composition Data					
PARAMETER	Concentration (ug/l)				
	OBS	10th	50th	90th	MAX
PHYSICAL/CHEMICAL PROPERTIES					
BOD	1	67	67	67	67
COD	1	489	489	489	489
TDS	1	2720	2720	2720	2720
Solids	20	1300000	3700000	5120000	5400000
pH (SU)	21	6.2	6.9	7.4	7.68
Nitrate/Nitrite	1	1.24	1.24	1.24	1.24
Nitrate	17	116.8	1800	7560	9900
Nitrite	8	12.8	19	325.6	936
Total Cyanide	1	13.9	13.9	13.9	13.9
Total Phenols	1	89	89	89	89
Total Sulfide (Iodometric)	1	27	27	27	27
TOC	1	189	189	189	189
TSS	1	22	22	22	22
TRACE ELEMENTS					
Metals					
Antimony	1	10.8	10.8	10.8	10.8
Arsenic	1	29.8	29.8	29.8	29.8
Barium	1	147.41	147.41	147.41	147.41
Boron	1	16250	16250	16250	16250
Calcium	1	280660	280660	280660	280660
Chloride	1	299	299	299	299
Chromium	1	9.88	9.88	9.88	9.88
Copper	1	28.64	28.64	28.64	28.64
Europium	1	9.88	9.88	9.88	9.88
Fluoride	1	0.2	0.2	0.2	0.2
Germanium	1	126.6	126.6	126.6	126.6
Gold	1	41.52	41.52	41.52	41.52
Iridium	1	75.35	75.35	75.35	75.35
Iron	1	5429.8	5429.8	5429.8	5429.8
Lead	1	28.06	28.06	28.06	28.06
Magnesium	1	138820	138820	138820	138820

Manganese	1	7151.5	7151.5	7151.5	7151.5
Neodymium	1	22.6	22.6	22.6	22.6
Niobium	1	80.62	80.62	80.62	80.62
Phosphorus	1	590.62	590.62	590.62	590.62
Potassium	1	74175.2	74175.22	74175.22	74175.22
Ruthenium	1	133.98	133.98	133.98	133.98
Samarium	1	111.78	111.78	111.78	111.78
Scandium	1	8.22	8.22	8.22	8.22
Selenium	1	1.7	1.7	1.7	1.7
Silicon	1	8265.17	8265.17	8265.17	8265.17
Sodium	1	365380	365380	365380	365380
Strontium	1	2904.6	2904.6	2904.6	2904.6
Sulfur	1	386573	386572.9	386572.9	386572.9
Thorium	1	146.06	146.06	146.06	146.06
Thulium	1	19.09	19.09	19.09	19.09
Titanium	1	5.85	5.85	5.85	5.85
Zinc	1	102.11	102.11	102.11	102.11
Organics					
Ammonia as Nitrogen	1	0.67	0.67	0.67	0.67
Chloroform	2	7.49	9.05	10.61	11
Disulfoton	1	4.42	4.42	4.42	4.42
Methylene chloride	1	6.2	6.2	6.2	6.2
MCPA	1	490	490	490	490
MCPP	1	490	490	490	490
Toluene	1	4.1	4.1	4.1	4.1
Trichloroethane	1	143.925	143.925	143.925	143.925
Trichlorofluoromethane	1	54	54	54	54
TPHC	4	2130	3300	4890	5100
1,1-Dichloroethane	2	5.54	6.5	7.46	7.7
1,1-Dichloroethene	2	13.4	15	16.6	17
1,1,1-Trichloroethane	1	5.8	5.8	5.8	5.8
Vinyl chloride	4	20.8	25	34.1	38
1,4-Dioxane	1	57.29	57.29	57.29	57.29

Data Source

Effluent Guidelines for Landfill Point Source Category: Mormon Hollow Site Visit Report, October 4, 1994.

LANDFILL CASE 14: NORTHERN STATES POWER WOODFIELD ASH MONOFILL

Identification

Name: Northern States Power Woodfield Ash Monofill
Physical address: Front Street
Ashland, WI 54806
Owner: Northern States Power (NSP)
Ownership status: Captive
Facility contact: Leroy Wilder, Jr., Coordinator, 715-839-2691
State license no.: 03233
Landfill type: Industrial (Combustion ash)
Permitting status: Active

Landfill Construction and Controls

Type of LCS: Standard with drainage blanket and geotextile
Number of phases: Five (5)
Status: Phases 1 and 2 are active Phases 3–5 have not been constructed
Liner type: 5 feet of compacted clay
Cover type: No final caps or covers
Operational period: March 1994 to present
Permitted wastes: Wood ash and coal ash from NSP plants
Overall location area: 240 acres
Permitted area: 9 acres
Total permitted capacity: 255,000 yd³ (includes waste and intermediate cover)
Estimated year of closure: 2009
Underlying geology/soil type: Surface soils are clay to clay loams underlain by sandy till and sandstone bedrock at a depth 250 feet
Depth to aquifer: 120 feet (confined)

Landfilled Waste

Nature of waste: Coal and wood combustion ash from NSP Bay Front Plant
Average annual quantity landfilled: 15,500 tons
Average annual volume landfilled: 15,900 yd³
Total cumulative quantity landfilled: 67,184 tons
Total cumulative volume landfilled: 69,172 yd³
Liquid to solid ratio: 0.05 L/kg

Leachate Quantity

Average leachate generation: Approximately 975,000 gallons
Average annual precipitation: 30 inches

Exhibit 1. Landfill Construction and Controls			
Phase	Status	Liner	Operational Period
1	Active	5 feet of compacted clay	March 1994 to present
2	Active		January 1994 to present
3	Proposed		

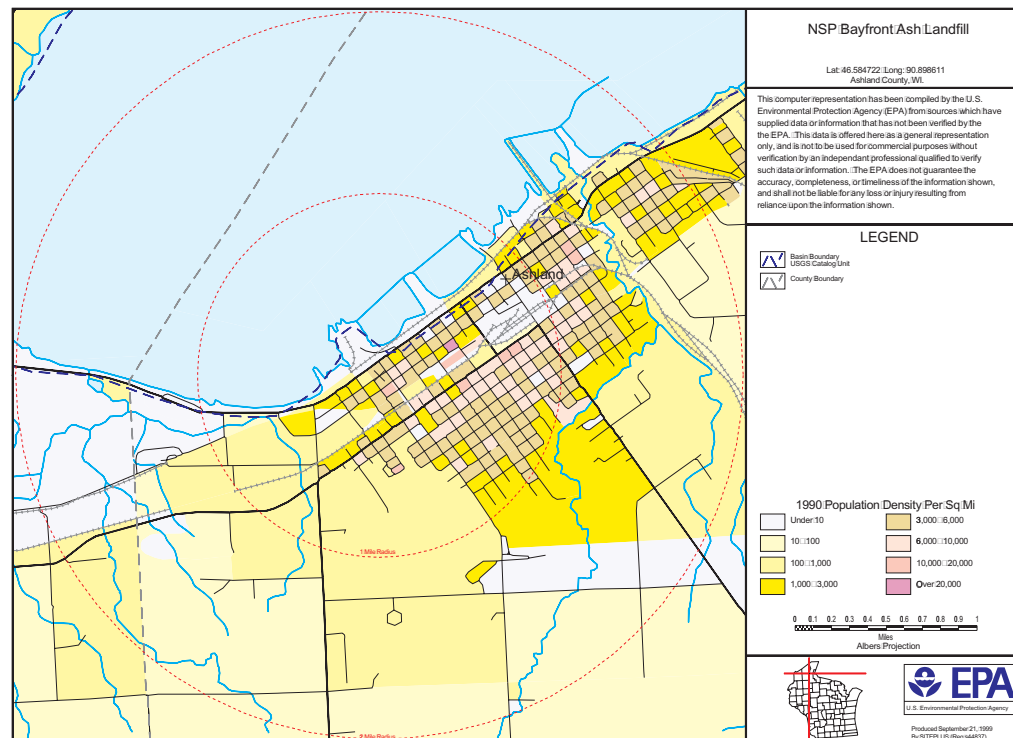


Exhibit 2. Waste Data		
Year	Quantity (tons)	Volume (yd ³)
1994	7,833	12,841
1995	12,079	13,421
1996	14,119	12,835
1997	18,000	16,300
1998	15,153	13,775

as of October 1998

Exhibit 3. Leachate Quantity Data					
Year	1994	1995	1996	1997	1998
Quantity (gallons)	12,000	834,000	2,196,000	978,000	863,000

Leachate Quality

Exhibit 4. Leachate Composition Data						
	Concentration (ug/l)					
PARAMETER	OBS	10th	50th	95th	MAX	% Detect
PHYSICAL/CHEMICAL PROPERTIES						
Alkalinity (mg/l as CaCO ₃)	12	548.9	2603.5	3825.25	4345	100%
BOD (mg/l)	26	3.5	22.3	157.5	210	100%
Chloride (mg/l)	12	120.7	489	1237	1435	100%
COD (mg/l)	12	56.7	309.5	2408.5	2700	100%
Hardness (mg/l as CaCO ₃)	11	69	97	299.5	359	100%
pH (su)	26	7.32	9.29	12.3975	12.44	100%
Specific Conductance (umho/cm)	23	242.848	3120	20090	23300	100%
Sulfate (mg/l)	12	665.5	5401.453	8952.041	9740	100%
TSS (mg/l)	26	6.1	80.4	303.25	431.2	100%
TRACE ELEMENTS						
Metals						
Arsenic	2	14	70	133	140	50%
Barium	7	35.472	140	258	300	100%
Boron (mg/l)	12	0.01	0.17665	17.32	38	83%
Calcium (mg/l)	3	19.76	28	42.4	44	100%
Chromium	2	4	20	38	40	50%
Fluoride (mg/l)	2	0.172	0.26	0.359	0.37	100%
Iron (mg/l)	12	0.246	1.625	7.825	11.4	100%
Lead	12	0	0	43.5	60	33%
Magnesium (mg/l)	2	4.66221	5.52345	6.492345	6.6	100%
Manganese	5	8.448	54.5	71.8	73	100%
Mercury	7	0	0.2	2.46	3	57%
Phenol	1	24	24	24	24	100%
Phosphorus (mg/l)	21	0.02	2.7	4	4.4	95%
Potassium (mg/l)	2	1807.9	3619.5	5657.55	5884	100%
Selenium	12	5.54	62	3260	7000	100%
Silver	7	0	0	14	20	14%
Sodium (mg/l)	2	264.4	510	786.3	817	100%
Sodium (mg/l)	2	264.4	510	786.3	817	100%

Data Source

Wisconsin Department of Natural Resources File review conducted by SAIC (September 1999)

LANDFILL CASE 15: WMWI TIMBERLINE TRAIL MUNICIPAL LANDFILL

Identification

Name: WMWI Timberline Trail Landfill
Address: P.O. Box 160
 Bruce, WI 54819
Owner: Waste Management of Wisconsin (WMWI)
Ownership status: Commercial
Facility contact: Scott O Neill, Site Manager, 715-868-7000
State license no.: 03455
Landfill type: Municipal Solid Waste (MSW)
Permitting status: Active

Landfill Construction and Controls

Type of LCS: Standard
Number of phases: Five (5)
Status: Portions of phases 1–4 are active
Liner type: 4 feet of compacted clay, 60 mil geomembrane, and geotextile
Cover type: Daily cover of petroleum contaminated soil
Estimated year of closure: 2006 (as of January 1997)
Operational period: January 5, 1995 to present
Waste acceptance: Municipal (MSW), asbestos, petroleum contaminated soil, demolition, coal combustion ash, foundry, and other non-hazardous wastes

Overall location area: 160 acres
Permitted area: 27 acres
Total permitted capacity: 2,933,000 yd³
Depth to aquifer: 25 feet
Special practice: Operate a bio-remediation facility on-site (store bio-waste in landfill prior to treatment).

Landfilled Waste

Nature of waste: MSW, asbestos, petroleum contaminated soil, demolition, coal combustion ash, foundry and other non-hazardous wastes including: filters, wood blocks, pre-treatment sludge and recycling rejects
Total cumulative quantity landfilled: 630,086 tons (as of January 1997)
Total cumulative volume landfilled: 777,495 yd³ (as of January 1997)
Liquid to solid ratio: 0.024 L/kg

Leachate Quantity

Average annual leachate generation: 2,054,000 gallons
Average annual precipitation: 32 inches

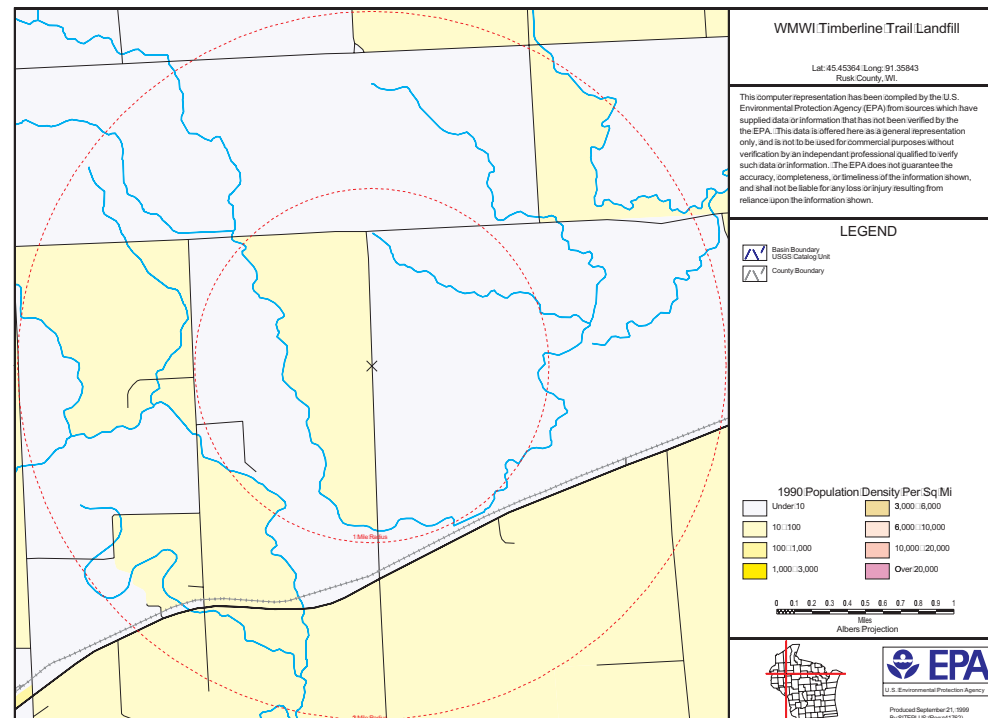


Exhibit 2. Waste Data

Year	Quantity (tons)	Volume (yd ³)
1995	76,859	118,244
1996	183,834	264,644
1997	232,590	357,830

Exhibit 1. Landfill Construction and Controls

Phase	Status	Liner	Operational Period
1	Active	4 feet of compacted clay, 60 mil geomembrane, and geotextile	Jan. 1995 to present
2	Active		Nov. 1997 to present
3	Active		Nov. 1996 to present
4	Active		Sept. 1998 to present
5	Proposed		

Exhibit 3. Leachate Quantity Data

Year	1995	1996	1997	1998
Quantity (gallons)	1,524,597	1,124,259	1,643,438	3,922,523

Leachate Quality

Exhibit 4. Leachate Composition Data						
PARAMETER	Concentration (ug/l)					
	OBS	10th	50th	95th	MAX	% Detect
PHYSICAL/CHEMICAL PROPERTIES						
Alkalinity (mg/l as CaCO ₃)	7	290	825	2319.4	2410	100%
BOD (mg/l)	49	273.6	2760	7165.6	8800	96%
Chloride (mg/l)	7	43.98	172	411.1	439	100%
COD (mg/l)	7	291.6	1720	6166	6340	86%
Hardness (mg/l as CaCO ₃)	7	283.2	1180	2679	2970	100%
Nitrate Nitrogen (mg/l)	3	0	0	0.0477	0.053	33%
Nitrogen, Ammonia (mg/l)	3	57.36	97.2	116.82	119	100%
Nitrogen, Kjeldahl (mg/l)	3	84.92	117	128.7	130	100%
pH (su)	49	5.362	6.26	6.906	7.04	100%
Specific Conductance (umho/cm)	49	794	2290	4160	4710	100%
Sulfate (mg/l)	7	8.58	26.5	84.77	91.1	86%
TSS (mg/l)	49	30.8	150	1692.4	20500	100%
TRACE ELEMENTS						
Metals						
Barium	6	0	328.5	5425	6870	67%
Beryllium	4	0	0	38.76	45.6	25%
Cadmium	7	0	1.2	3.32	3.5	57%
Chromium	6	14.45	35.45	1546.5	2020	100%
Cobalt	4	19.5	68.9	979.92	1140	75%
Copper	6	0	19.5	3919.5	5210	67%
Fluoride (mg/l)	2	0.248	0.44	0.656	0.68	100%
Iron (mg/l)	7	21.512	107	1693.4	2330	100%
Lead	5	0	0	184.8046	231	40%
Manganese	7	5328	21400	31680	32100	100%
Mercury	7	0	0	1.96	2.8	14%
Nickel	6	44.9	78.2	2377.5	3120	100%
Phosphorus (mg/l)	47	0.3332	0.92	3.814	5.76	100%
Potassium (mg/l)	2	38.11	64.15	93.445	96.7	100%
Selenium	6	0	0	9.95	11.4	33%
Sodium (mg/l)	7	44.7	140	366.4	367	100%
Vanadium	4	0	31.25	3103.375	3640	50%
Zinc	6	62.75	643.5	9905	12600	100%
Organics						
1,1,1-Trichloroethane	7	4.2	32	123.8	140	86%
1,1-Dichloroethane	7	0	25	60.9	63	57%
1,1-Dichloroethylene	7	9	55	193.2	240	86%

2-Hexanone	7	0	32	179	200	57%
4-Methyl-2-pentanone (mibk)	7	50.4	190	247	250	86%
Acetone	7	126	2500	5930	6500	86%
Arsenic	6	4.15	10.9	75.3	88.9	83%
Benzene	7	0	0	4.4	5	29%
Carbon Tetrachloride	7	0	0	28	40	14%
Chloroethane	7	0	10	25.8	30	57%
Chloromethane	7	0	0	2.8	4	14%
cis-1,2-dichloroethene	7	0	0	6.1	7	29%
Dichlorodifluoromethane	7	0	0	1.4	2	14%
Dichloromethane	7	144	720	1606	1900	100%
Diethyl Phthalate	2	4.5	22.5	42.75	45	50%
Ethylbenzene	7	0	9	35.7	39	57%
Fluorotrichloromethane	7	0	0	25.1	35	29%
Methyl Ethyl Ketone (MEK)	7	566	4400	8470	8500	100%
Methyl Tert-butyl Ether (MTBE)	7	0	0	3.7	4	29%
Naphthalene	7	0	0	5.6	8	14%
o-dichlorobenzene	7	0	0	0.7	1	14%
p-dichlorobenzene	7	0	0	2.4	3	29%
Phenol	2	338	610	916	950	100%
Phenolics	1	818	818	818	818	100%
Styrene	7	0	2	21	27	57%
Tetrachloroethylene	7	0	3	6.4	7	57%
Tetrahydrofuran	7	268	570	1156	1300	100%
Toluene	7	96.8	310	1088	1400	100%
Trichloroethylene (tce)	7	0	5	17.8	22	57%
Vinyl Chloride	7	0	0	11.2	13	29%
Xylenes	7	22.8	68	178	190	86%

Data Source

Wisconsin Department of Natural Resources File review conducted by SAIC (September 1999)

LANDFILL CASE 16: WAUPACA FOUNDRY MONOFILL

Identification

Name: Waupaca Foundry Monofill
 Address: Granite alley and Elm alley Roads
 Waupaca, WI 54981
 Owner: Waupaca Foundry, Inc.
 Ownership status: Captive
 Facility contact: Jeffrey Loeffler, Environmental Coordinator, 715-258-6611
 State license no.: 03412
 Landfill type: Industrial (Foundry)
 Permitting status: Active

Landfill Construction and Controls

Type of LCS: Standard with 1-foot drainage layer and geotextile
 Number of phases: Three (3)
 Status: Phase 2 and 3A are active
 Liner type: 5 feet of compacted clay
 Operational period: April 1994 to present
 Estimated year of closure: 2004 (as of Jan. 1997)
 Waste acceptance: Accepts only high volume foundry waste from Waupaca Foundry including system sand, slag, WWT cakes, core sands, cleaning room wastes and refractories

Permitted area: 19.5 acres
 Total permitted capacity: 1,493,000 yd³
 Underlying geology/soil type: Surface soils include sandy loams underlain by granite bedrock at 100 feet
 Special practices: In August of 1995, began re-using leachate as dust suppressant on waste prior to landfilling

Landfilled Waste

Nature of waste: Foundry system sand, slag, WWT cakes, core sands, cleaning room waste and refractories
 Total cumulative quantity landfilled: 526,716 tons (as on January 1997)
 Total cumulative volume landfilled: 462,782 yd³ (as of January 1997)
 Liquid to solid ratio: 0.033 L/kg (based on 1995 data)

Leachate Quantity

Average annual leachate generation: 2,520,000 gallons
 Average annual precipitation: 32 inches

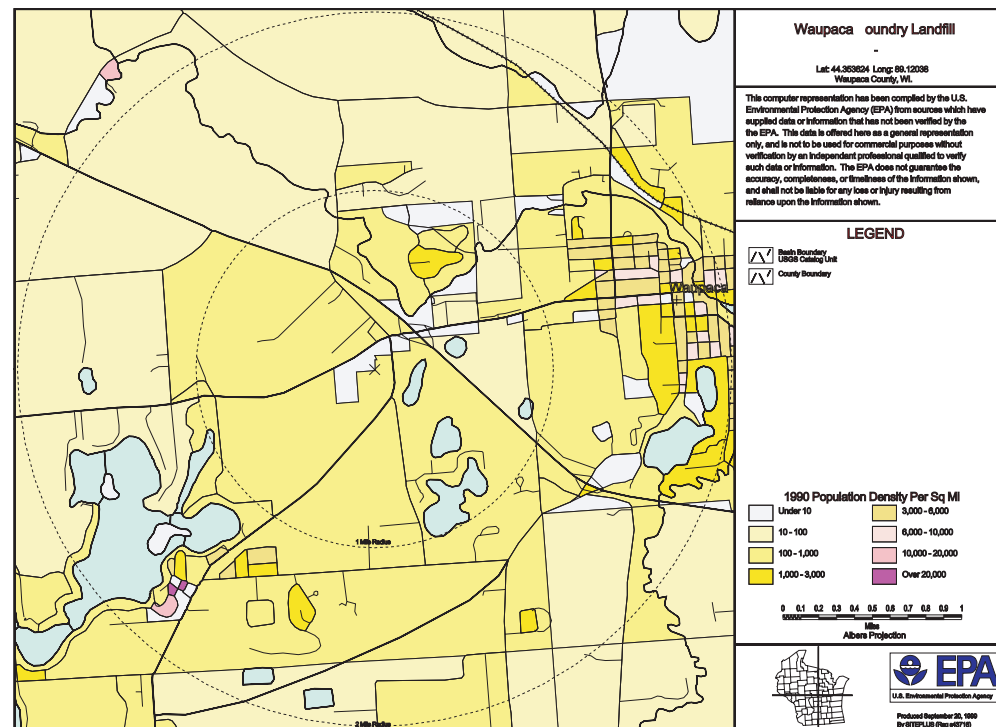


Exhibit 1. Landfill Construction and Controls

Phase	Status	Liner	Operational Period	Final Cover	Estimated Waste Capacity (yd ³)
1A	Closed	5 feet of compacted clay	April 1994 to Late 1996	6 inches compacted clay, 30 inch rooting one, 6 inch top soil	274,000
1B	Closed		1995 to Late 1998	1 foot compacted clay, 30 inch rooting one, 6 inch top soil	
2	Active		August 1995 to present	N/A	267,800
3A	Active		Late 1996 to present	N/A	792,000
3B	Proposed				

Exhibit 2. Waste Data

Waste Type	Quantity (tons)	Volume (yd ³)	Year
Foundry waste	221,886	164,360	1994
	119,197	160,916	1995
	185,633	137,506	1996

Exhibit 3. Leachate Quantity Data

Year	1994	1995	1996
Quantity (gallons)	2,109,698	2,931,857	945,648

Quantity for January through March only

Leachate Quality

Exhibit 4. Leachate Composition Data						
PARAMETER	Concentration (ug/l)					
	OBS	10th	50th	95th	MAX	% Detect
PHYSICAL/CHEMICAL PROPERTIES						
Alkalinity (mg/l as CaCO ₃)	17	180	230	284	300	100%
BOD (mg/l)	17	0	0	14	26	47%
Chloride (mg/l)	17	156	230	548	740	100%
COD (mg/l)	17	26.4	42	101.2	110	100%
Hardness (mg/l as CaCO ₃)	17	280	350	570	610	100%
Nitrogen, Ammonia (mg/l)	3	0.098	0.25	0.34	0.35	100%
Nitrogen, Kjeldahl (mg/l)	4	0.748	1.15	2.745	3	100%
pH (su)	17	7.26	7.57	7.802	7.81	100%
Specific Conductance (umho/cm)	17	1860	2300	2880	3200	100%
Sulfate (mg/l)	17	326	570	1200	1200	100%
TSS (mg/l)	17	5.6	12	298	530	100%
TRACE ELEMENTS						
Metals						
Barium	3	35	55	67.6	69	100%
Cadmium	5	0	0	0.464	0.58	20%
Chromium	3	1.088	1.8	3.42	3.6	100%
Copper	3	4.48	8	17.9	19	100%
Cyanide (mg/l)	3	0.003	0.015	0.0303	0.032	67%
Fluoride (mg/l)	5	1.552	4.6	5.68	5.8	100%
Iron (mg/l)	5	0.284	0.58	2.72	3.1	100%
Lead	17	0	3.4	49.2	94	82%
Manganese	5	372	800	1080	1100	100%
Nickel	3	1.72	2.2	5.35	5.7	100%
Phosphorus (mg/l)	3	0.102	0.17	0.404	0.43	100%
Potassium (mg/l)	3	5.1	7.1	8.9	9.1	100%
Sodium (mg/l)	17	248	400	506	730	100%
Zinc	3	20.2	25	101.5	110	100%
Organics						
1,3,5-Trimethylbenzene	4	0	0	0.102	0.12	25%
Benzene	4	0	0	0.2805	0.33	25%
Dichloromethane	4	0	0	0.136	0.16	25%
Isopropylbenzene	4	0	0	0.187	0.22	25%
Methyl tert-butyl Ether (mtbe)	4	0	0	0.2635	0.31	25%
Naphthalene	4	0	0	0.3145	0.37	25%

Data Source

Wisconsin Department of Natural Resources File review conducted by SAIC (September 1999)

LANDFILL CASE 17: WESTSIDE RECYCLIN AND DISPOSAL LANDFILL

Identification

Name: Westside Recycling and Disposal Facility
 Address: 60050 Roberts Road
 Three Rivers, MI 49093
 Owner: Waste Management of Michigan, Inc.
 Ownership status: Commercial
 Facility contact: Eric Shafer, Site Operator, 616-279-5444
 EPA ID: MID985634583
 Landfill types: Subtitle D and Construction and Demolition Debris (C&D)
 Permitting status: Active

Landfill Construction and Controls

Type of LCS: Network of drains overlain on the liners in each landfill leachate is conveyed through force mains to an on-site above ground aeration tank

Number of landfills: Four (4)

Regulatory permitting controls: Permitted to operate a Type II—sanitary waste landfill and a Type III construction and demolition landfill by the Michigan Department of Natural Resources (MIDNR)

Waste acceptance: Customer must prepare a waste analysis plan and perform any necessary analysis required by WM or the MIDNR to properly identify the waste stream prior to acceptance at the landfill for disposal

Overall location area: 220 acres

Permitted area: 122.5 acres

Permitted capacity (active landfill): 7.8 million yd³ (Type II Sanitary)

Run-on/off controls: 1 foot of intermediate clay cover placed on the outside slopes

Underlying geology/soil type: 30 feet of sand and gravel

Depth to aquifer: 16 feet

Landfilled Waste

Nature of waste: Cells 1–13: municipal waste, non-hazardous industrial waste, asbestos, sewage sludge (Type II)
 C&D LF: construction and demolition waste (Type III)

Average annual volume landfilled: Cells 8–13: 1,014,000 yd³

Total cumulative volume landfilled: Cells 1–4: 1,900,000 yd³
 Cells 8–13: 2,750,000 yd³
 C&D LF: 265,000 yd³

Total cumulative quantity landfilled: 3,650,000 tons

Liquid to solid ratio: 0.007 L/kg

Leachate Quantity

Average annual leachate generation: 6,000,000 gallons

Average annual precipitation: 35.2 inches

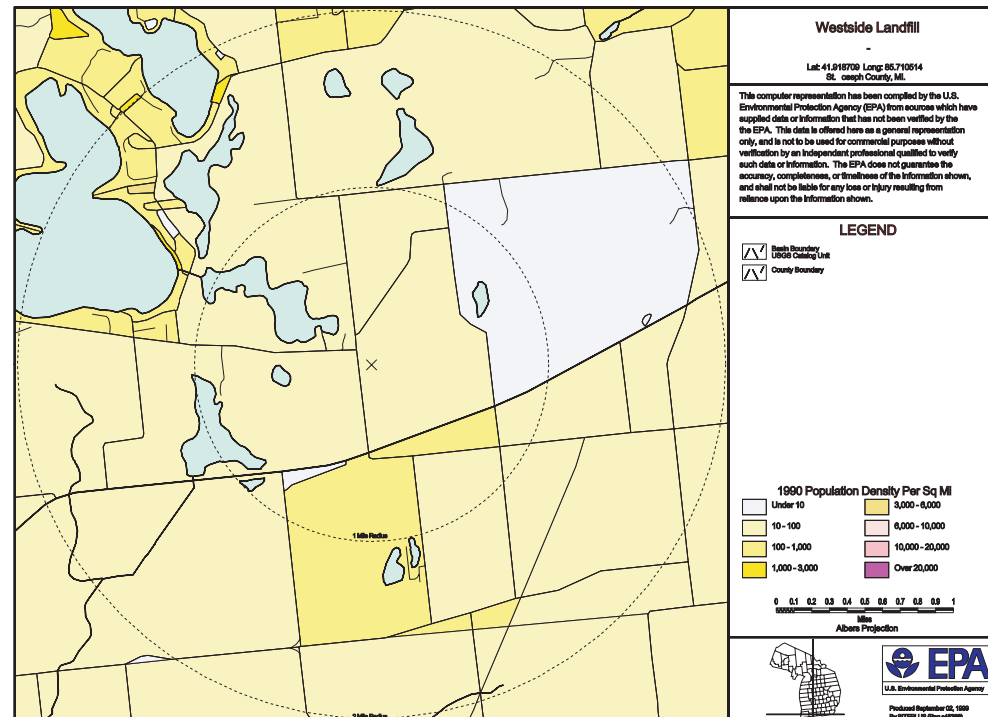


Exhibit 1. Landfill Construction and Controls

Landfill Type/Area	Cell(s)	Status	Liner	LCS	Cover	Operational Period
Type II (Sanitary)/ 17 acres		Closed	None	None	2 feet compacted clay, topsoil, vegetative cover	1960–1986
Type II (Sanitary)/ 32.5 acres	1–4a	Closed	Single 30-mil P C liner	LCS	Composite cap of P C liner and one foot compacted clay	1985–1994
	4b		Double 30-mil P C liner	Primary LCS and leak detection system		
Type II (Sanitary)/ 67 acres	5–7	Not yet constructed	Not yet constructed	Primary LCS and secondary leak detection system	None	N/A Start: July 1993
	8–13	Active	Double composite liner			
Type III (C&D)/ 6 acres		Active	30-mil P C liner	LCS	None	Start: 1989

Leachate Quality

Exhibit 2. Leachate Composition Data					
PARAMETER	Concentration (ug/l)				
	OBS	10th	50th	90th	MAX
PHYSICAL/CHEMICAL PROPERTIES					
COD	1	14	14	14	14
TDS	1	466	466	466	466
pH	2	7.003	7.015	7.027	7.03
Nitrate/Nitrite	1	1.34	1.34	1.34	1.34
TRACE ELEMENTS					
Metals					
Arsenic	1	3.1	3.1	3.1	3.1
Barium	1	92.2	92.2	92.2	92.2
Boron	1	97.4	97.4	97.4	97.4
Calcium	1	126000	126000	126000	126000
Chloride	2	7264.3	36213.5	65162.7	72400
Fluoride	1	0.17	0.17	0.17	0.17
Iron	1	4960	4960	4960	4960
Magnesium	1	28600	28600	28600	28600
Manganese	1	1600	1600	1600	1600
Potassium	1	3010	3010	3010	3010
Silicon	1	3270	3270	3270	3270
Sodium	1	15000	15000	15000	15000
Strontium	1	200	200	200	200
Sulfur	1	9850	9850	9850	9850
Zinc	1	16	16	16	16
Organics					
Ammonia as Nitrogen	2	60101.2	300500.1	540900.1	601000
Dalapon	1	6.3	6.3	6.3	6.3
Dicamba	1	10.4	10.4	10.4	10.4
Dichlorprop	1	4.7	4.7	4.7	4.7
Dinoseb	1	3.1	3.1	3.1	3.1
Methylbenzene	1	110	110	110	110
m-xylene	1	51	51	51	51
p-xylene	1	50	50	50	50

Picloram	1	1.4	1.4	1.4	1.4
Toluene	1	520	520	520	520
2,4-D	1	4.8	4.8	4.8	4.8
2,4-DB	1	9.4	9.4	9.4	9.4
2,4,5-T	1	2.2	2.2	2.2	2.2
2,4,5-TP	1	5.5	5.5	5.5	5.5

Data Source

Effluent Guidelines for Landfill Point Source Category: Westside Site Visit Report, May 26, 1995.

LANDFILL CASE 18: WINNEBAGO COUNTY SUNNYVIEW MUNICIPAL LANDFILL

Identification

Name: Winnebago County Sunnyview Landfill
 Address: 100 West County Road
 Oshkosh, WI 54901
 Owner: Winnebago County
 Ownership status: Municipal
 Facility contact: Henry Sommer, Superintendent, 414-424-0793
 State license no.: 03175
 Landfill types: Municipal Solid Waste (MSW) and Industrial (Paper mill sludge)
 Permitting status: Active

Landfill Construction and Controls

Type of LCS: Standard
 Number of phases: MSW/sludge landfill — Six (1–6)
 Sludge landfill — Four (A–D)
 Status: Phases 1–4 (MSW/sludge) and A–D (sludge) are active
 Liner type: Double-lined 5 feet and 3 feet of clay with a granular drainage blanket between the two liners
 Operational period: January 1989 to present
 Proposed year of closure: 2010
 Waste acceptance: MSW/sludge landfill — municipal, commercial, and industrial solid waste
 Sludge landfill — pulp/paper mill sludge
 Overall location area: 213 acres
 Permitted area: MSW/sludge landfill — 74 acres
 Sludge landfill — 28 acres
 Cell dimensions: MSW/sludge landfill — 400 feet wide by 1,100 feet long
 Sludge landfill — 200 feet wide by 800 feet long
 Total permitted capacity: MSW/sludge landfill — 7,783,500 yd³
 Sludge landfill — 1,260,100 yd³
 Underlying geology/soil type: Surface soils are silty clay to clay underlain by dolomite bedrock

Landfilled Waste

Nature of waste: Municipal, commercial, and industrial solid waste including: garbage, refuse, combustible and non-combustible demolition wastes, brush, trees and pulp/paper mill sludge
 Total cumulative quantity landfilled: 2,037,153 tons (as of January 1997)
 Average annual quantity: 226,400 tons
 Total cumulative volume landfilled: 3,287,010 yd³ (as of January 1997)
 Average annual volume: 365,200 yd³
 Liquid to solid ratio: 0.029 L/kg

Leachate Quantity

Average annual leachate generation: 16,484,000 gallons
 Average annual precipitation: 29.5 inches

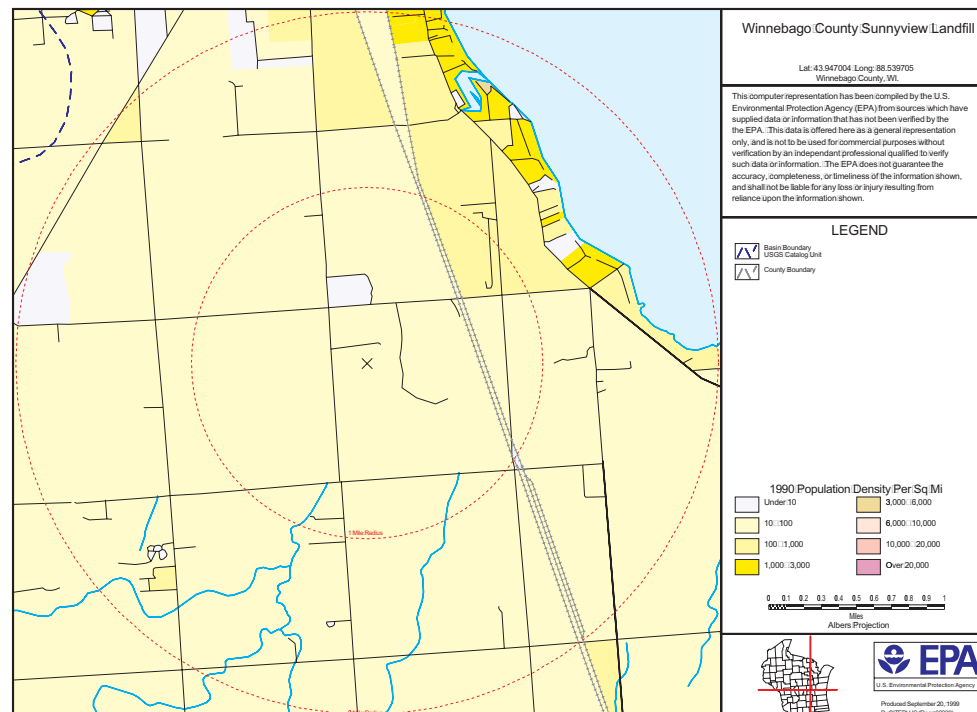


Exhibit 1. Landfill Construction and Controls

Landfill Type	Phase	Status	Liner	Design Capacity (yd ³)
MSW/sludge	1–4	Active	5 feet of clay overlain by a drainage blanket and 3 feet of clay	6,276,716 (MSW)
	5–6	Constructed		641,937 (sludge)
Sludge	A–D	Active		1,260,100

Exhibit 2. Waste Data

Wastes Type	Cumulative Quantity (tons)	Cumulative Volume (yd ³)
MSW	1,315,170	2,630,340
Pulp/paper mill sludge	721,983	656,670

As of January 1997

Leachate Quality

Exhibit 3. Leachate Composition Data						
PARAMETER	Concentration (ug/l)					
	OBS	10th	50th	95th	MAX	% Detect
PHYSICAL/CHEMICAL PROPERTIES						
Alkalinity (mg/l as CaCO ₃)	153	305	775	5018.4	8020	100%
BOD (mg/l)	335	0	106	8047.5	22650	68%
Chloride (mg/l)	154	19	57.5	903.6	1260	100%
COD (mg/l)	262	0	24	5024.6	25402	69%
Hardness (mg/l as CaCO ₃)	155	457.2	1200	4683.9	9400	100%
Nitrite plus Nitrate (mg/l)	103	0	1	8.69	14	83%
Nitrogen, Ammonia (mg/l)	109	0	0.14	265.6	333	67%
Nitrogen, Kjeldahl (mg/l)	103	0.262	0.94	327	400	90%
pH (su)	339	6.3	6.9	8	8.7	100%
Specific Conductance (umho/cm)	337	700	1740	7642	12000	100%
Sulfate (mg/l)	154	3.13	150.5	1075	3400	92%
Sulfite (mg/l)	10	0	0	1	1	20%
TSS (mg/l)	336	7	55	329.25	716	96%
TRACE ELEMENTS						
Metal						
Arsenic	16	0	16.5	167	500	69%
Barium	16	100	480	1400	1700	88%
Cadmium	20	0	0	11.25	16	20%
Chromium	16	0	0	74.75	89	13%
Copper	16	0	15	112.25	149	75%
Cyanide (mg/l)	16	0	0.0055	0.067	0.067	56%
Iron (mg/l)	131	0.21	10	201.5	322	99%
Lead	20	0	0	7.65	115	15%
Manganese	131	0.04	225	2760	6800	91%
Mercury	20	0	0	0.405	0.5	20%
Nickel	16	0	57	280	310	75%
Phosphorus (mg/l)	235	0.04	1.1	2.43	15	95%
Potassium (mg/l)	16	34.5	98	187.25	239	100%
Selenium	16	0	0	9.235	34	13%
Sodium (mg/l)	105	15	51	998.4	58000	100%
Zinc	16	0	52.5	1042.5	1440	75%
Organics						
1,1,1-Trichloroethane	32	0	0	0.5835	21.2	9%
1,1-Dichloroethane	32	0	0	3.965	6.4	13%
1,2,4-Trimethylbenzene	10	0	0.425	19.2	21	50%
1,2-Dichloroethane	32	0	0	0	0.42	3%
1,3,5-Trimethylbenzene	10	0	0	8.13	8.4	30%
2,4-Dimethylphenol	6	0	0	10.5	14	17%
2-Methylnaphthalene	6	0	0	8.375	9.5	33%
Acetone	12	0	0	123.3	274	8%

Anthracene	6	0	0	1.5	2	17%
Benzene	32	0	0	5.665	11	19%
Benzoic Acid	6	0	139	1155	1400	67%
Bis(2-ethylhexyl) Phthalate (Dehp)	6	0	0	17.25	23	17%
Butylbenzene, n-	10	0	0	1.9885	3.1	20%
Carbon Disulfide	12	0	0	10.35	23	8%
Chlorobenzene	32	0	0	0.54	1.9	6%
Chloroethane	32	0	0	4.685	12	9%
Chloroform	32	0	0	0.72	83.4	6%
Chloromethane	32	0	0	0	4.7	3%
cis-1,2-Dichloroethene	30	0	0	0.936	1.1	13%
Cresols	4	306	845	1332.5	1400	100%
Dichlorodifluoromethane	24	0	0	14.45	18.4	8%
Dichloromethane	32	0	0	4.6	9.8	13%
Diethyl Phthalate	6	0	2.85	78.75	100	50%
Di-n-butyl Phthalate	6	0	0	5.1	6.8	17%
Endosulfan Sulfate	4	0	0.0065	0.03425	0.038	50%
Endrin	4	0	0.00465	0.00981	0.0099	50%
Ethylbenzene	32	0	0	35.55	56	22%
Heptachlor	4	0	0	0.007735	0.0091	25%
Isophorone	6	0	0	5.925	7.9	17%
Isopropylbenzene	10	0	0	4.565	4.7	30%
m-cresol (3-methylphenol)	2	188	224	264.5	269	100%
Methyl Tert-butyl Ether (mtbe)	26	0	0	1.725	3	8%
m-xylene	2	0.34	1.7	3.23	3.4	50%
Naphthalene	30	0	0	56.15	69	27%
n-propylbenzene	10	0	0	3.015	3.6	30%
o-cresol (2-methylphenol)	2	0.72	3.6	6.84	7.2	50%
o-dichlorobenzene	32	0	0	0	0.3	3%
o-xylene	2	0.18	0.9	1.71	1.8	50%
p-dichlorobenzene	32	0	0	10.9	42	13%
Phenanthrene	6	0	0	6	8	17%
Phenol	6	0	0	129.225	170	33%
Phenolics	101	0	0.021	219	686	61%
p-isopropyltoluene	10	0	1.8	9.84	12	50%
Styrene	26	0	0	0	0.8	4%
Tetrahydrofuran	12	0	0	750.1	771	33%
Toluene	32	0	0	80.4	300	41%
Trichloroethylene (tce)	32	0	0	169.75	508	13%
Vinyl Chloride	32	0	0	1.725	5.9	13%
Xylenes	26	0	0	113.5	130	27%

Data Source

Wisconsin Department of Natural Resources File review conducted by SAIC (September 1999)

LANDFILL CASE 19: SUPERIOR MUNICIPAL LANDFILL

Identification

Name:

Superior Landfill

Address:

3001 Little Neck Road
Savannah, A 31419
Tel: 912-927-6113

Owner/Operator:

Superior (a Waste Management Company since 1991)

Ownership status:

Commercial

Facility contact:

Mike Cooper, 912-927-6113

State agency contact:

Harold illespie,
A Environmental Protection Division,
404-362-2692

EPA ID:

A0001896810

State permit no.:

025-070D

Landfill type:

Municipal Solid Waste (MSW)

Permitting status:

Active

Landfill Construction and Controls

Type of LCS:

Sump/riser

Number of cells:

8 (upon completion)

Status:

Only 1 active cell

Liner type:

Clay and synthetic liners (geonet also)

Cover type:

6 inch daily cover

Operational period:

March 1994 to present

Waste acceptance:

Accepts residential, commercial, and industrial waste such as contaminated soils and process wastes, asbestos, POTW sludges, and municipal incinerator ash

Overall location area:

742 acres

Permitted area:

90 acres

Underlying geology/soil type:

Tight, fine sand underlain with an 8–14 inch marine clay layer

Special practices:

Currently vertically expanding an unlined 26-acre cell.

Landfilled Waste

Nature of waste:

Residential or commercial (75–80%), industrial waste (20–25%)

Average annual quantity landfilled:

Unknown

Total cumulative quantity landfilled:

147,000 tons (March–October 1994)

Liquid to solid ratio:

0.027 L/kg

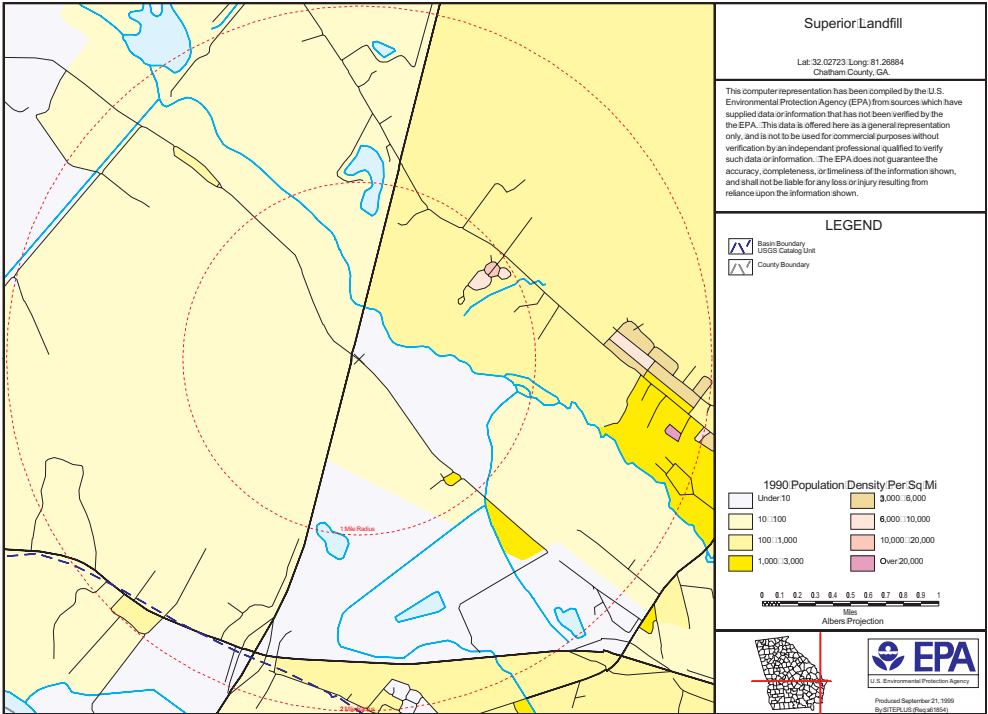
Leachate Quantity

Annual leachate generation:

1,014,500 gallons (only 8 months of leachate collection)

Average annual precipitation:

50.7 inches



Leachate Quality

Exhibit L. Leachate Composition Data					
PARAMETER	Concentration (ug/l)				
	OBS	10 th	50 th	90 th	MAX
PHYSICAL/CHEMICAL PROPERTIES					
BOD	6	1090.00	1135.00	1340.00	1340.00
COD	6	1450.00	1520.00	1600.00	1600.00
TDS	6	2400.00	2420.00	2590.00	2590.00
pH	6	6.92	7.00	7.04	7.04
Nitrate/Nitrite	6	1.07	1.15	2.02	2.02
Total Organic Carbon (TOC)	6	584.00	674.00	692.00	692.00
Total Phenols	6	1230.00	1265.00	1310.00	1310.00
Total Phosphorous	6	0.02	0.02	0.03	0.03
Total Sulfide (Iodometric)	6	7.80	10.65	16.00	16.00
Total Suspended Solids	6	27.00	203.00	223.00	223.00
TRACE ELEMENTS					
Metals					
Aluminum	6	55.70	74.10	92.50	92.50
Arsenic	6	13.60	16.60	16.80	16.80
Barium	4	0.20	0.30	0.33	0.33
Boron	6	1760.00	1790.00	1860.00	1860.00
Cadmium	6	4.10	4.10	4.10	4.10
Calcium	6	330000.00	333000.00	352000.00	352000.00
Chloride	6	264.00	277.50	283.00	283.00
Hexavalent chromium	6	0.04	0.04	0.06	0.06
Fluoride	6	0.13	0.40	0.45	0.45
Iron	6	90600.00	93550.00	97700.00	97700.00
Lead	6	78.80	114.40	150.00	150.00
Magnesium	6	89200.00	90550.00	94500.00	94500.00
Manganese	6	4580.00	4615.00	4900.00	4900.00
Nickel	6	15.00	17.20	18.10	18.10
Potassium	6	73000.00	75300.00	76300.00	76300.00
Silicon	6	4280.00	4300.00	4430.00	4430.00
Sodium	6	261000.00	264500.00	275000.00	275000.00
Strontium	6	1370.00	1395.00	1440.00	1440.00
Sulfur	6	3630.00	4005.00	4470.00	4470.00
Yttrium	6	2.50	2.80	4.50	4.50
Zinc	6	10.20	13.10	19.60	19.60
Organics					
Acetophenone	6	10.64	10.64	10.64	10.64
Alachlor	4	0.25	0.25	0.25	0.25

Alpha-Terpinol	6	43.16	44.36	47.20	47.20
Ammonia as Nitrogen	6	15.40	69.00	73.00	73.00
Benzoic Acid	6	6957.72	7411.37	8903.46	8903.46
Chlorothalonil	4	0.28	0.28	0.28	0.28
Diallate A	4	2.16	4.56	6.95	6.95
Diallate B	4	40.50	40.50	40.50	40.50
Diethyl ether	6	84.759	89.643	98.142	98.142
Dioxathion	4	35.00	35.00	35.00	35.00
Diphenyldisulfide	4	14.00	14.50	46.00	46.00
Disulfoton	4	14.00	14.50	46.00	46.00
Ethylbenzene	6	30.748	32.997	34.509	34.509
Gamma-BHC	4	0.19	0.25	0.33	0.33
Hexamethylphosphoramide	4	7.06	7.14	7.40	7.40
Hexane extractable material	4	5.00	5.50	6.00	6.00
Hexanoic acid	6	4939.19	5842.33	6963.05	6963.05
MCPA	4	58.00	79.60	328.00	328.00
MCPP	4	73.00	243.50	933.00	933.00
Naled	4	8.00	8.00	8.00	8.00
p-Cresol	6	677.59	767.40	935.41	935.41
Phenol	6	426.10	578.03	1228.84	1228.84
Phosphamidon E	4	5.00	5.50	6.00	6.00
Propachlor	4	0.70	0.81	1.48	1.48
Terbuthylazine	7	10.10	11.30	12.50	12.50
Toluene	6	361.35	382.26	385.16	385.16
Trichlorofluoromethane	6	3182.72	3182.72	3182.72	3182.72
Tripropyleneglycol methyl ether	6	1138.16	1177.10	1328.03	1328.03
Vinyl chloride	6	15.12	19.08	21.36	21.36
1,2-Dibromo-3-chloropropane	10	0.22	0.22	0.22	0.22
1,4-Dioxane	6	10.67	12.06	13.45	13.45
2-Butanone	6	2792.24	3325.35	3597.29	3597.29
2-Propanone	6	968.99	1592.17	2223.35	2223.35
2,4-D	4	1.90	12.65	23.40	23.40
2,4-DB	4	5.00	9.10	14.20	14.20
2,4,5-T	4	0.30	0.60	0.80	0.80
2,4,5-TP	4	0.30	11.50	40.10	40.10
4-Chloro-3-Methylphenol	6	188.22	188.22	188.22	188.22
4,4-Methyl-2-pentanone	6	321.885	396.312	429.714	429.714

Data Source

Effluent Guidelines for Landfill Point Source Category: Superior Sampling Event, May 25, 1995.

LANDFILL CASE 20: NORTHWOODS SANITARY LANDFILL

Identification

Name: Northwoods Sanitary Landfill
Address: 1750 24th Street
Rice Lake, WI 54686-8735
Owner: Northwoods
Ownership status: Commercial
Facility contact: Gregory Snider, President, 715-458-4565
State license no.: 03212
Landfill type: Municipal Solid Waste (MSW)
Permitting status: Active

Landfill Construction and Controls

Type of LCS: Standard with 1-foot drainage blanket
Number of phases: Three (3)
Status: Phase 1 and 2 active
Liner type: 5 feet of clay and 60 mil HDPE geomembrane
Estimated year of closure: 2011 (as of January 1997)
Operational period: October 1993 to present
Waste acceptance: Municipal solid waste
Permitted area: 10.5 acres
Total permitted capacity: 500,000 yd³
Underlying geology/soil type: Sandstone/quartzite bedrock overlain by loam
Depth to aquifer: 40–200 feet

Landfilled Waste

Nature of waste: Municipal solid waste
Total cumulative quantity landfilled: 29,010 tons (as of January 1997)
Total cumulative volume landfilled: 136,521 yd³ (as of January 1997)
Liquid to solid ratio:

Leachate Quantity

Average annual leachate generation: 1,300,000 gallons
Average annual precipitation: 32.2 inches

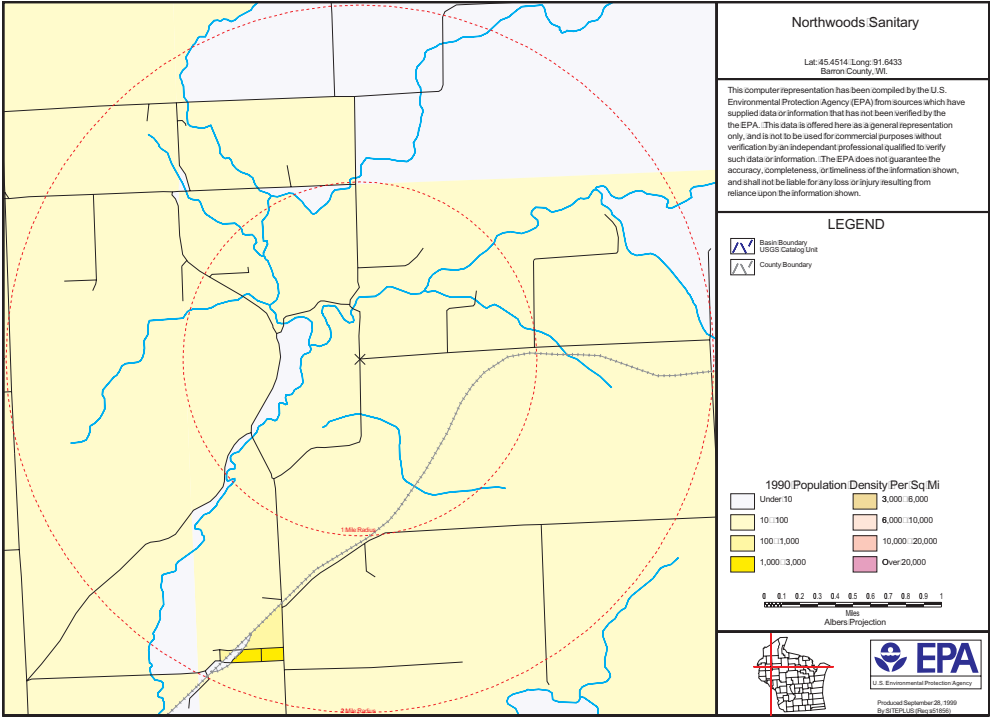


Exhibit 1. Waste Data			
Wastes Type	Quantity (tons)	Volume (yd³)	Year
MSW	0.25	1.17	1993
MSW	4,151	19,534	1994
MSW	13,737	64,646	1995
MSW	11,122	52,340	1996

Began operations in October of 1993

Exhibit 2. Leachate Volume Data					
Year	1994	1995	1996	1997	1998
Volume (gallons)	1,298,900	1,231,200	1,320,900	N/A	698,600

Quantities for January through June only.

Leachate Quality

Exhibit 3. Leachate Composition Data						
PARAMETER	Concentration (ug/l)					
	OBS	10th	50th	95th	MAX	% Detect
PHYSICAL/CHEMICAL PROPERTIES						
Alkalinity (mg/l as CaCO ₃)	11	1400	2520	4406.5	4463	100%
BOD (mg/l)	42	370.8	2165	6181.5	8580	100%
Chloride (mg/l)	11	379	773	1185	1220	100%
COD (mg/l)	11	1400	7600	13750	13800	100%
Hardness (mg/l as CaCO ₃)	11	1700	2330	3475	3890	100%
Nitrogen, Ammonia (mg/l)	11	99	263	375	398	100%
Nitrogen, Kjeldahl (mg/l)	3	264.2	325	328.6	329	100%
pH (su)	45	6.572	7.2	7.68	9.91	100%
Specific Conductance (umho/cm)	10	3670	6284	10235	11000	100%
Sulfate (mg/l)	3	108.8	144	183.6	188	100%
TSS (mg/l)	45	171.4	324	543.2	636	100%
TRACE ELEMENTS						
Metals						
Benzene	2	6.13	6.25	6.385	6.4	100%
Cadmium	3	0	0	1.26	1.4	33%
Iron (mg/l)	11	75.2	268	350.5	387	100%
Manganese	3	6.832	11.2	2818.12	3130	100%
Mercury	3	0	0	0.0027	0.003	33%
Phosphorus (mg/l)	8	1.01	2.05	4.495	5.3	100%
Sodium (mg/l)	3	769.2	770	779.9	781	100%
Organics						
1,1-Dichloroethane	2	7.83	12.35	17.435	18	100%
1,2,4-Trimethylbenzene	2	13.4	15	16.8	17	100%
1,3,5-Trimethylbenzene	2	0.73	3.65	6.935	7.3	50%
cis-1,2-dichloroethene	1	38	38	38	38	100%
Ethylbenzene	2	58.1	62.5	67.45	68	100%
m,p-xylene	2	131	135	139.5	140	100%
Methyl Tert-butyl Ether (MTBE)	2	0.97	4.85	9.215	9.7	50%
o-xylene	2	49.1	49.5	49.95	50	100%
Toluene	2	292	460	649	670	100%
Vinyl Chloride	2	0.97	4.85	9.215	9.7	50%

Data Source

Wisconsin Department of Natural Resources File review conducted by SAIC (September 1999)

LANDFILL CASE 21: ERNON COUNTY MUNICIPAL LANDFILL

Identification

Name: ernon County Municipal Landfill
 Address: Route 3
 Box 247B
 iroqua, WI 54665
 Owner: ernon County
 Ownership status: Municipal
 Facility contact: eorge Nettum, Chairman, 608-634-2900
 State license no.: 03268
 Landfill type: Municipal Solid Waste (MSW)
 Permitting status: Active

Landfill Construction and Controls

Type of LCS: Standard with 1-foot sand drainage layer
 Number of phases: 3 Phases composed of 9 modules
 Status: Phase 1 (modules 1 and 2) — active
 Phase 2 (module 1) — active
 Liner type: Composite (5 feet compacted clay and 60 mil HDPE geomembrane)
 Operational period: October 1993 to present
 Waste acceptance: Residential, commercial, non-hazardous industrial wastes from ernon County
 Overall location area: 158 acres
 Permitted area: 10 acres
 Max waste depth: 25 feet
 Total permitted capacity: 314,942 yd³ (283,448 yd³ of waste)
 Underlying geology/soil type: Silty, well-drained loess underlain by clays, pebbles and dolomite bedrock
 Depth to aquifer: 180 feet

Landfilled Waste

Nature of waste: garbage, refuse, animal carcasses, asbestos, and demolition
 Total cumulative quantity landfilled: 25,804 tons
 Total cumulative volume landfilled: 50,825 yd³
 Liquid to solid ratio: 0.027 L/kg

Leachate Quantity

Average leachate generation: 186,176 gallons
 Average annual precipitation: 32.5 inches

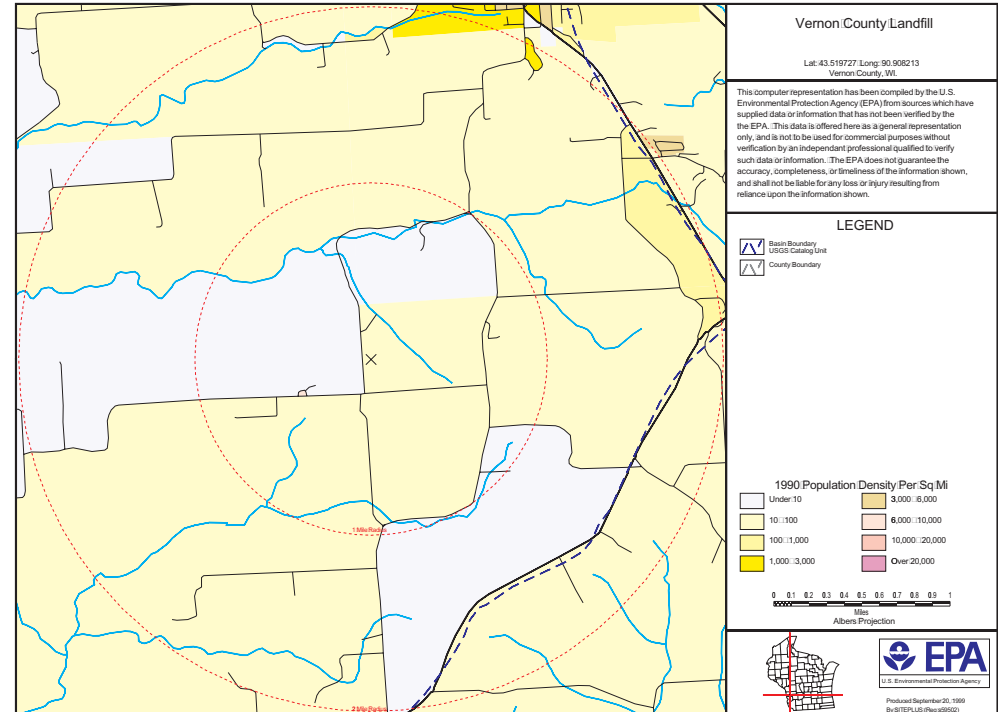


Exhibit 1. Landfill Construction and Controls				
Phase	Modules	Status	Operational Period	Estimated Waste Capacity (yd ³)
1	1	Active	October 1993 to present	32,376
	2		Early 1996 to present	33,699
2	1	Active	Late 1998 to present	25,272
	2-3	Proposed		56,870
3	1-4	Proposed		135,231

Exhibit 2. Waste Data			
Waste Type	Quantity (tons)	Volume (yd ³)	Year
MSW	2,368	4,736	1993
	7,852	15,704	1994
	7,366	14,732	1995
	7,435	14,870	1996
Petro contaminated soil	783	783	

Leachate Quality

Exhibit 3. Leachate Composition Data						
PARAMETER	Concentration (ug/l)					
	OBS	10th	50th	95th	MAX	% Detect
PHYSICAL/CHEMICAL PROPERTIES						
Alkalinity (mg/l as CaCO ₃)	7	800	1300	3230	3500	100%
BOD (mg/l)	26	2.5	55	745	940	92%
Chloride (mg/l)	8	226.2	861	2422.5	3000	100%
COD (mg/l)	9	127.94	850	1447.2	1500	100%
Hardness (mg/l as CaCO ₃)	8	658	865	2530	3300	100%
Nitrite plus Nitrate (mg/l)	5	0	0	31.868	39.7	40%
pH (su)	24	6.693	7.425	8.2325	8.96	100%
Specific Conductance (umho/cm)	23	338.8	1515.67	8548	8731	100%
Sulfate (mg/l)	5	3.6	24.5	287.2	349	80%
TSS (mg/l)	28	10.8	59.5	530.6	7400	96%
TRACE ELEMENTS						
Metals						
Antimony	5	0	3.6	6.82	7.2	60%
Arsenic	5	15.04	22	56.6	58	100%
Barium	5	626	910	1596	1670	100%
Beryllium	5	0	0	3.2	4	20%
Cadmium	5	0	0	2	2.5	20%
Chromium	5	10.006	63	299	350	100%
Cobalt	5	0	0	38.29	46	40%
Copper	5	0	0	15	16	40%
Fluoride (mg/l)	4	0.003	1.545	18.533	21.26	75%
Iron (mg/l)	8	3.42	19	65.325	65.5	100%
Lead	4	0.508	3.845	11.25	12	100%
Manganese	4	1118	3650	29950	34300	100%
Mercury	5	0	0	3.2	4	20%
Nickel	4	16.2	59.5	128.75	140	75%
Phosphorus (mg/l)	26	0.0935	0.4635	4.5	5.8	96%
Selenium	4	3.6	13	19.1	20	75%
Silver	4	0	0	1.955	2.3	25%
Sodium (mg/l)	4	303.82	260410	562500	570000	100%
Vanadium	4	0	7	27.6	30	50%
Zinc	4	60.94	97.9	142.5	150	100%
Organics						
1,1,1-Trichloroethane	5	0	0	2.08	2.6	20%
1,1-Dichloroethane	5	0	0	113.2	141	40%
1,2,4-Trimethylbenzene	5	0	0	2.44	2.7	40%

1,2-Dichloroethane	5	0	0	0.4	0.5	20%
1,3,5-Trimethylbenzene	5	0	0	0.9	1	40%
Benzene	5	0	0	4.9	6	40%
Chloroethane	5	0	0	2.48	3.1	20%
Chloromethane	5	0	0	6.24	7.6	40%
cis-1,2-dichloroethene	5	0	0	4.56	5.7	20%
Ethylbenzene	5	0.6	3.4	5.72	6.1	80%
Isopropylbenzene	5	0	0	1.62	2	40%
m,p-xylene	5	0	1.3	7.82	8.9	60%
Methyl Tert-butyl Ether (MTBE)	5	0	0	2.78	3.2	40%
Naphthalene	5	0	1.7	1.9	1.9	60%
o-xylene	5	0.32	1.8	4.64	5.2	80%
p-dichlorobenzene	5	0.08	1.2	7.04	8.1	80%
p-isopropyltoluene	5	0	0	2.14	2.6	40%
Styrene	5	0	0	4.24	5.3	20%
Toluene	5	0.08	4	69.94	70	80%

Data Source

Wisconsin Department of Natural Resources File review conducted by SAIC (September 1999)

LANDFILL CASE 22: TAN IPAHOA PARISH MUNICIPAL LANDFILL

Identification

Name: Tangipahoa Parish Landfill
 Address: 57510 Hano Road
 Independence, LA 70443
 Owner: Tangipahoa Parish Council
 Ownership status: Municipal
 Facility contact: Buddy Till, Landfill Manager, 504-878-6332
 Charles Hedges, Consultant (Delta Engineers)
 NPDES ID: LA0078921
 State permitNo.: P-0127
 Landfill type: Municipal Solid Waste (MSW)
 Permitting status: Active

Landfill Construction and Controls

Type of LCS: Standard
 Number of cells: Five (5)
 Status: Cell 4 is active
 Liner type: 3-feet of compacted clay (cells 1–4)
 Final cover type: 2-feet of compacted clay (temporary site and cells 1–3)
 Operational period: 1981 to present
 Waste acceptance: Accepts only non-hazardous municipal solid waste and limited amounts of construction & demolition (C&D) debris
 Overall location area: 100 acres
 Permitted area: 44 acres
 Cell dimensions: 500 ft long by 700 ft wide by 40 ft deep (cell 4)
 Run-on/off controls: Run-on control, run-off control (designed for 25-yr, 24-hr storm event)
 Underlying geology/soil type: Impervious clay
 Depth to aquifer: 3 feet

Landfilled Waste

Nature of waste: Municipal or commercial non-hazardous solid waste (70%), yard wastes (15%), agricultural waste (other than pesticides) (10%), C&D debris (3%) and sewage sludge (2%)
 Average annual quantity landfilled: 45,760 tons
 Total cumulative quantity landfilled: 569,264 tons
 Liquid to solid ratio: 0.007 L/kg

Leachate Quantity

Average annual quantity generated: 1,092,000 gallons
 Average annual precipitation: 66 inches

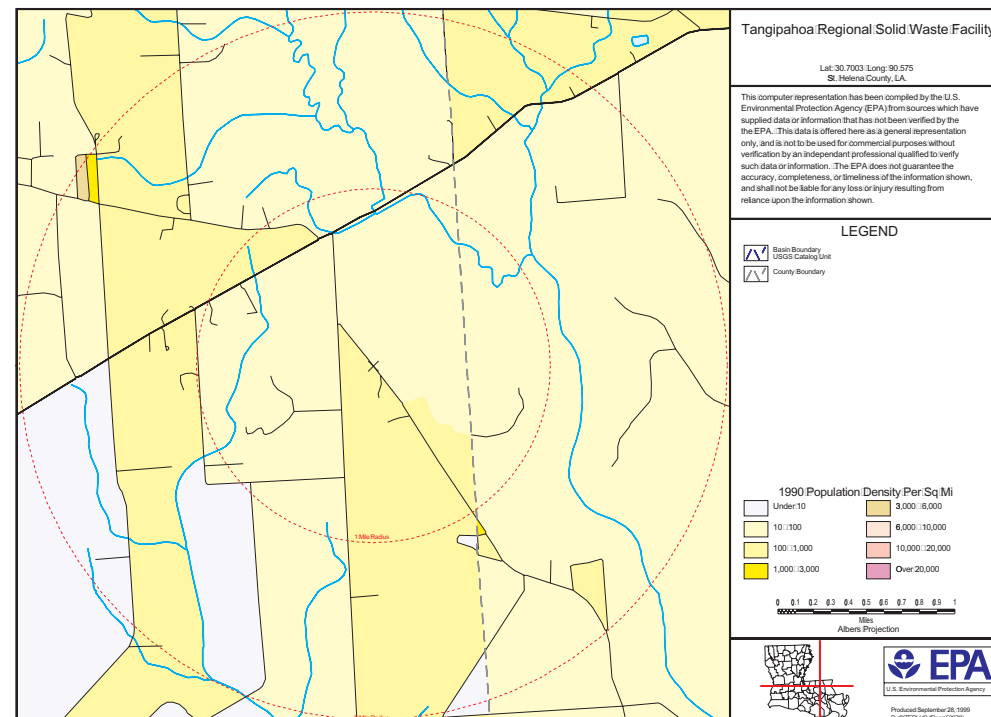


Exhibit 1. Landfill Construction and Controls				
Phase	Status	Liner	Operational Period	Final Cover
Temporary site	Closed	Naturally occurring clay base	1981 to 1984	2 feet of compacted clay
1		3 feet of compacted clay	1984 to 1986	
2			1986 to 1988	
3			1989 to 1993	
4	Active		1993 to present	N/A

Leachate Quality

Exhibit 2. Leachate Composition Data					
PARAMETER	Concentration (ug/l)				
	OBS	10 th	50 th	90 th	MAX
PHYSICAL/CHEMICAL PROPERTIES					
BOD	2	131.4	153	174.6	180
COD	2	1109	1545	1981	2090
TDS	1	5400	5400	5400	5400
pH (su)	2	7	7	7	7
Nitrate/Nitrite	2	1	1	1	1
Total Phenols	2	127.6	146	164.4	169
Total Phosphorus	2	5.3	6.5	7.7	8
Total Sulfide (Iodometric)	1	76	76	76	76
TOC	2	168.8	208	247.2	257
TSS	2	5806	14470	23134	25300
TRACE ELEMENTS					
Metals					
Aluminum	2	50380	111100	171820	187000
Arsenic	2	9.5	19.1	28.7	31.1
Barium	2	1208	1760	2312	2450
Beryllium	2	1.79	4.15	6.51	7.1
Boron	2	2550	3910	5270	5610
Cadmium	1	18.1	18.1	18.1	18.1
Calcium	2	142500	184500	226500	237000
Cerium	1	1900	1900	1900	1900
Chloride	2	398.4	728	1057.6	1140
Chromium	2	98.36	210.2	322.04	350
Cobalt	2	49.7	50.9	52.1	52.4
Copper	2	67.7	138.5	209.3	227
Fluoride	2	1.1	1.5	1.9	2
Iron	2	100980	184100	267220	288000
Lanthanum	1	681	681	681	681
Lead	2	90.06	216.7	343.34	375
Magnesium	2	83990	99550	115110	119000
Manganese	2	2036	3620	5204	5600
Mercury	2	0.391	0.955	1.519	1.66
Neodymium	1	937	937	937	937
Nickel	2	103.92	148.4	192.88	204

Phosphorus	2	125400	223000	320600	345000
Silicon	2	63180	91100	119020	126000
Sodium	2	458500	792500	1126500	1210000
Strontium	2	736.6	787	837.4	850
Sulfur	2	11583	19635	27687	29700
Vanadium	2	174.4	476	777.6	853
Yttrium	3	106.68	397	583.4	630
Titanium	2	80.35	91.75	103.15	106
Zinc	1	1360	1360	1360	1360
Zirconium	1	124	124	124	124
Organics					
Ammonia as Nitrogen	2	652	2900	5148	5710
Biphenyl	1	200	200	200	200
Disulfoton	1	14	14	14	14
Ethylbenzene	2	15.5705	16.8325	18.0945	18.41
Hexane extractable material	1	26	26	26	26
Hexanoic acid	1	20.834	20.834	20.834	20.834
MCPA	1	201	201	201	201
Methylene chloride	1	10.686	10.686	10.686	10.686
OCDD	2	1238.33	5576.85	9915.37	11000
p-cresol	2	22.4832	48.376	74.2688	80.742
Terbuthylazine	1	28.3	28.3	28.3	28.3
Toluene	2	37.5793	48.1845	58.7897	61.441
Tripropyleneglycol methyl ether	2	991.1637	1235.0985	1479.0333	1540.017
m-xylene	1	13.803	13.803	13.803	13.803
1234678-HPCDD	2	36.528	126.96	217.392	240
12 34678-HPCDF	1	56	56	56	56
123678-HXCDD	1	0.174	0.174	0.174	0.174
123789-HXCDD	1	0.464	0.464	0.464	0.464
2-Butanone	2	75.6861	90.9305	106.1749	109.986
2-Propanone	2	105.1182	109.859	114.5998	115.785
2,4,5-T	1	1.1	1.1	1.1	1.1

Data Source

Effluent Guidelines for Landfill Point Source Category: Tangipahoa Site Visit Report, February 4, 1994.

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Additional Works for Further Study

During review of literature for this report several authors cited reports that appeared to discuss critical issues in more detail. Such sources are listed below and represent literature that can be obtained and reviewed to better investigate these areas.

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Farquhar, et al. "Temporal Characterization of MSW Leachate." *Canadian Journal of Civil Engineering*, **19**, 668-679. 1992. *(Expected to continue MSW aging research described in the 1989 work.)*

Francis, A.J.; C. J. Dodge; and J. B. Gillow. *Nature*, **356**, 140-142. 1992. *(Expected to discuss volatile fatty acids and their influence on contaminant leaching.)*

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McGinley, P. and P. Kmet. *Formation, Characteristics, Treatment, and Disposal of Leachate from MSW Landfills*. Bureau of Solid Waste Management, Wisconsin Department of Natural Resources, Madison, 1984. *(Expected to discuss volatile fatty acids and their influence on contaminant leaching.)*

Wigh, Richard J. *Comparison of Leachate Characteristics from Selected Municipal Solid Waste Test Cells*." Project Summary. U.S. Environmental Protection Agency, September 1984. EPA-600/S2-84-124. *(Expected to provide additional data regarding temporal variability of MSW leachate.)*

APPENDIX A. REVIEW OF STATE LANDFILL LEACHATE DATA AVAILABILITY

State	Facility Type	Contact	Data Quality	Availability
AK	Hazardous and Non-Hazardous	Heather Stockard Solid Waste Management	Handful of LF's collect leachate. Several pages of data in each quarterly monitoring reports	FOIA
AL	Non-Hazardous	Andy Baker DEM/Land Division	No reporting requirement Small amount of data for over 200 facilities	On-site file review and copy
	Subtitle C	Michael Champion DEM - Haz. Waste Section	No reporting requirement and very limited data for the only Subtitle C LF	On-site file review and copy
AR	Hazardous and Non-Hazardous	Rhonda Sharp Poll. Control & Ecology/Office of Pub. Affairs	Data on file at office but no published reports or electronic formats, ~50 LF's and 1 Subtitle C LF	On-site file review and copy
AZ	Non-Hazardous (no Subtitle C)	Technical Staff Solid Waste Section	Limited monitoring data but not compiled	24 hour notice for file review
CA	Non-Hazardous	Bart Simmons	State requires leachate data from LF's	To receive published data
	Subtitle C	Bill Veile EPA/ Hazardous Waste	State requires monthly leachate recovery reports	On-site file review and copy
CO	Non-Hazardous	Glenn Mallory Solid Waste Management Division	State collects data on five LF's	On-site file review and copy

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State	Facility Type	Contact	Data Quality	Availability
	Subtitle C	Tanell Roberts Haz. Materials & Waste Mgmt. Division	State does not collect leachate data	N/A
CT	Ash (no Subtitle C)	John England DEP	State requires quarterly reports for three ash LF's with data on file at office	On-site file review and copy
DE	Non- Hazardous	Dennis Murphy Solid Waste Branch	Leachate data from five LF's in electronic format	Data through Delaware Solid Waste Authority and need written request (FOIA)
	Subtitle C	Alex Ritberg Hazardous Waste Branch	Collect data from one double-lined LF on bi-annual basis	FOIA or side-step FOIA by copying thru EPA Region 3
FL	Non- Hazardous (no Subtitle C)	Lisa Martin DEP/ Bureau of Solid and Hazardous Waste	State requires leachate reporting, 279 active non- hazardous LF's with 178 of this total being C&D LF's	To receive ~10 mb of data in electronic format and 1 1993 report
GA	Non- Hazardous (no Subtitle C)	Pete Dasher DNR/Solid Waste Program	Data on file for only a handful of the state's ~100 LF's; overall no reporting requirement	On-site file review and copy
	Municipal	Harold Gillespie DEP (Land Protection)	Limited data (only some groundwater data); stated that the best source of data was the facility	On-site file review at regional office
HI	Hazardous and Non- Hazardous	George Tabil Office of Solid Waste	Data submitted if specified in permit, 13 active and 15 closed LF's	Contact each LF for data

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State	Facility Type	Contact	Data Quality	Availability
IA	Non-Hazardous (no Subtitle C)	Doc Holiday	Leachate data available by permit number	On-site file review and copy
ID	Hazardous and Non-Hazardous	Phil Ferguson DEQ	State collected limited leachate data	FOIA
IL	Non-Hazardous	Sar Rastaberg EPA/Landfills Section	Data collected by state but no published reports/summaries or electronic formats, database to be constructed within the year	FOIA
	Subtitle C	Sean Chisek EPA/Haz. Waste	State does not require leachate monitoring until post-closure, 3 Subtitle C LF's	Contact each LF for limited data
IN	Hazardous and Non-Hazardous	Ghodrat Hiadari DNR/Solid Waste	Report leachate data quarterly or annually but not compiled, do not require leachate characterization, ~50 Non-Haz LF's and 1 closed Subtitle C	On-site file review and copy
KS	Non-Hazardous (no Subtitle C)	Joe Kronan DHE/Bureau of Waste Mgmt.	Annual analysis reporting, reports on file at office	On-site file review and copy Call Phil Rosewicz for additional information
KY	Non-Hazardous (No Subtitle C)	Mary Gowens DEP/Division of Waste Management	Require quarterly reports which include leachate volume and characterization data, 33 LF's	Contact Maria Wood at (502) 564-6716 ext. 210 for file review or On-site file review and copy
*LA	Non-Hazardous	Brett LeBlanc DEQ/Solid Waste Division	Require annual leachate data reports for 213 parameters, currently only one report and no data in electronic format	To receive LF report Copy additional data at office

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State	Facility Type	Contact	Data Quality	Availability
	Subtitle C	Narendra Dave DEQ/Haz. Waste Division	Two active LF's required to report quarterly, files contain large amount of data but no published reports or electronic formats	On-site file review and copy
MA	Hazardous and Non-Hazardous	Abdul Turray DEP	Contact initiated	
	C&D	Mark Haley DEP -Western Region	Hardcopy files for each landfill within each region including limited waste and leachate quality	On-site file, however, was able to fax limited data regarding one specific landfill
MD	Non-Hazardous	Edward Dexter Department of Environment/ Solid Waste	Require annual reporting of leachate volumes and characterization data for the 43 LF's, files date back to early 1980's, files are not organized	Send written request to Public Information Acts Section (FOIA)
	Subtitle C	Amin Yazdanian Department of Environment/ Hazardous Waste	Require semi-annual data reports, no active and 2 closed LF's	FOIA
ME	Hazardous and Non-Hazardous	Bill Butler DEP	Contact initiated	
*MI	Non-Hazardous	Becky Kocsis DEQ/Waste Management	Quarterly reporting required, Districts (10 total) hold leachate data	Send written requests (and in some cases need FOIA) to district offices - method varies from district to district

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State	Facility Type	Contact	Data Quality	Availability
	*Subtitle C	Dee Montgomery DEQ/Waste Management	Annual reporting required since 1982, data centralized and on file, leachate data focuses on characterization, wide range of facilities - petroleum, chemical manufacturing, auto, commercial	On-site file review and copy
*MN	Hazardous and Non-Hazardous	Shelly Burman Pollution Control Agency/Envi. Outcomes	Leachate reporting data required containing constituent concentrations	To receive leachate data in report format
*MO	Non-Hazardous	Tom Roscetti DEQ/Solid Waste Mgmt. Program	No longer require leachate data reports, some of 43 LF's data on file at office	On-site file review and copy
	Subtitle C	Rob Morrison DEQ/Haz. Waste Mgmt. Program	Require reporting from the only active LF, also office has data for at least 2 more closed LF's, data not compiled	On-site file review and copy
MS	Hazardous and Non-Hazardous	Milton Brumfield DEQ/Off of Poll. Control	Leachate data (volumes and constituents) reported monthly if required by permit, data entered into USEPA PCS database, approximately 20 Subtitle D and 1 Subtitle C	On-site file review and copy, Subtitle C data at LF
MT	Hazardous and Non-Hazardous	Pat Crowley Office of Solid Waste Program	Limited data because few LF's collect leachate data, not published or electronic	On-site file review and copy, soon to be compiled
NE	Non-Hazardous (no Subtitle C)	Ralph Martin DEC/Land Quality Div.	Volume and constituent data on file	On-site file review and copy

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State	Facility Type	Contact	Data Quality	Availability
NV	Munic.	Ed Wojcik Clark County Health District	State has only one LF generating leachate (Apex), Clark County collects leachate data on this LF, data not compiled in report or electronic format	Send written request to Records Office (\$0.60/pg) or call for file review appointment
	Subtitle C	Greg Lovato DEP	State collects data on the only HW LF (US Ecology), Quarterly reporting since 4/97, all leachate is F039, on file at office	On-site file review and copy or send written request
*NH	Non-Hazardous (no Subtitle C)	David Russo Solid Waste Section	Leachate data required monthly from approximately eight LF's	Contact Ariel Parent at (603) 271-2900 in the Public Information Office for file review
*NJ	Hazardous and Non-Hazardous	Gary Torres Industrial Users Unit Elenaor Kurkoski LF Coord NP Source	State has database of leachate data since 1993 of non-urban facilities, not much QA/QC documentation, hard to link waste and leachate	Have old data integrated in all NJPDES monitoring, new data goes to POTW, she will try and identify new cells for case study. Alternatively contact Bureau of Permits Mgmt. for archival data
NM	Non-Hazardous (No Subtitle C)	Jerry Bober Environment Dept./Solid Waste Bureau	No data - reporting not required	N/A
NY	Hazardous and Non-Hazardous	Robert Bhenof	Contact initiated	
NC			Contact initiated	

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State	Facility Type	Contact	Data Quality	Availability
ND	Hazardous and Non-Hazardous	Kevin Solie Division of Waste Mgmt.	Some data with permit files	Send letter requesting data to Division Director or copy at office
*OH	Non-Hazardous	Annette Dehavilland DEQ/Solid & Infectious Waste Division	Require annual data, setting up database in next few years, no published data	On-site file review and copy
	Subtitle C	Shannon Neighbors DEQ/Northwest District Office	Office requires the only Subtitle D LF (Envirosafe) in the state to report quarterly, 80 to 90% K061 waste	To receive data
OK	Hazardous and Non-Hazardous	Don Barrett DEQ/Waste Mgmt. Div.	Only 1 Subtitle C LF in state, require quarterly reporting of leachate data, raw data including characterization and volumes on file at office, no reporting requirement and limited data for 40+ non-hazardous LF's	FOIA or file review at \$0.15/pg
OR	Hazardous and Non-Hazardous	Bruce Decelye Waste Mgmt. Division (Salem Region)	Salem regional office collects substantial amounts of leachate data which is subsequently entered into USEPA Office of Water's STORET database (probably groundwater, not leachate, data)	FOIA
*PA	Hazardous and Non-Hazardous	Terry Killian Land Recycling & Waste Mgmt.	Chemical analysis data on file from ~75 LF's, several Subtitle C LF's but no commercial facilities	On-site file review and copy
*RI	Non-Hazardous (no Subtitle C)	Chris Schaffler Waste Management	Data collected quarterly from six LF's, one LF manages 80% of state waste	Contact Technical Assistance at (401) 222-6822 for file review and send request in writing

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State	Facility Type	Contact	Data Quality	Availability
SC	Hazardous and Non-Hazardous	John Litton Dept. of Health and Environmental Control	1 Subtitle C LF with limited leachate data	
SD	Non-Hazardous (no Subtitle C)	Rassool Ahadi Waste Mgmt. Program	Data not collected by state	Contact each facility for leachate data
TN			Contact initiated	
TX	Non-Hazardous	Arten Avakian TNRCC/ Municipal Solid Waste	No reporting requirement and no central repository, limited data	On-site file review and copy
	Subtitle C	Terese Jimenez TNRCC/ Industrial & Haz. Waste	Data held by each LF group, no centralized system and no published reports or databases	On-site file review and copy
UT	Non-Hazardous	Philip Burns Division of Solid & Haz. Waste	Limited data with only one LF (Salt Lake County) analyzing leachate, considered atypical leachate	Contact Salt Lake County LF directly for leachate analysis
	Subtitle C	Ed Costomiris Division of Solid & Haz. Waste	Limited data available but no reports or databases	On-site file review and copy
VT			Contact initiated	

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State	Facility Type	Contact	Data Quality	Availability
VA	Subtitle D & monofills	Hassan Vakili DEQ/Waste Program	No leachate sampling requirements for ~80 LF's, no database or published reports	Examine permit and then obtain data from regional offices
	C&D	Katherine Glass DEQ Roanoke Regional office	No database exists; only data required to report and available in permitting documents including: waste quantities and unit characteristics. Little to no leachate quality data.	File review at regional office
WA	Hazardous and Non-Hazardous	Kip Eagles Department of Ecology/Solid Waste	Office does not collect data, County Health Departments collect non-hazardous LF data	N/A
WV	Non-Hazardous (no Subtitle C)	Greg Rode Water Resources	State does not collect leachate data, limited data possibly included in USEPA's PCS database	On-site file review and copy
*WI	Hazardous and Non-Hazardous	Jack Connelly DNR/Waste Management Alt. Diane Stocks	Semi-annual reporting required, very extensive database of leachate quality data from 1970's to present, 2 reports with leachate data	To receive two reports containing leachate data, possible to query extensive database by site or leachate type but need written request
WY	Hazardous and Non-Hazardous	Ken Schreuder Solid & Haz. Waste Division	State currently has no leachate data	N/A

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APPENDIX B. RELEVANT CONVERSION FACTORS

Tons/Cubic Yards Conversion Sheet*

(Wisconsin Department of Natural Resources permitting material)

1. Municipal solid waste	
As delivered	
Domestic	425
Commercial	375
Industrial	300
Bulky	400
Trees and brush	300
Demolition	1,250
Liquids	8.34 lbs/gal
Compacted in place	1,000
Facility receiving only	
demolition waste	1,400
2. Municipal wastewater sludge	8.34 lbs/gal
3. Municipal incinerator ash	
As delivered - uncompacted	1,500
In field - compacted	2,700
4. Pulp and papermill sludge	
As delivered - uncompacted	1,800
In field - compacted	2,200
5. Utility ash - fly and bottom	
As delivered - uncompacted	2,200
In field - compacted	2,400
6. Foundry wastes	
As delivered - uncompacted	2,600
In field - compacted	3,000

**units are lbs./cu yd unless otherwise noted*

APPENDIX B. RELEVANT CONVERSION FACTORS

Tons/Cubic Yards Conversion Sheet*

(Wisconsin Department of Natural Resources permitting material)

1. Municipal solid waste	
As delivered	
Domestic	425
Commercial	375
Industrial	300
Bulky	400
Trees and brush	300
Demolition	1,250
Liquids	8.34 lbs/gal
Compacted in place	1,000
Facility receiving only	
demolition waste	1,400
2. Municipal wastewater sludge	8.34 lbs/gal
3. Municipal incinerator ash	
As delivered - uncompacted	1,500
In field - compacted	2,700
4. Pulp and papermill sludge	
As delivered - uncompacted	1,800
In field - compacted	2,200
5. Utility ash - fly and bottom	
As delivered - uncompacted	2,200
In field - compacted	2,400
6. Foundry wastes	
As delivered - uncompacted	2,600
In field - compacted	3,000

**units are lbs./cu yd unless otherwise noted*

APPENDIX C. L/S RATIOS AND LEACHATE GENERATION RATES REPORTED IN LITERATURE

Data summary: Readily available articles from the literature were searched to identify information regarding leachate generation rates from actual landfills. Typically, three pieces of data were required to calculate a L/S ratio or a normalized leachate generation rate: (1) total quantity of leachate generated in a period of time (e.g., annually), (2) landfill area, and (3) waste volume or average depth. Five articles were found with sufficient data to calculate one or more of these parameters. All focused on MSW landfills.

- Eighteen L/S ratios from six references are available. The median of the reported values is approximately 0.03/yr; the range is from 0.003 to 1.91/yr.
- Eight normalized leachate generation rates from three data sources are also available. The median of these values is approximately 130 gal/ac-d; the range is 27 to 620 gal/ac-d.

These data serve as a way to compare the Office of Water data to “actual” cases. Additionally, they provide a way to identify trends in the data. Trends observed from these data sources are as follows:

- The highest L/S ratios (0.5 to 2/yr from Reference 1) are generated from relatively small quantities of waste, no more than 350 MT. In Reference 5, the highest L/S ratio was also generated from the smallest landfill. Very high leachate generation rates would otherwise be required for large quantities of waste.
- Operational status was specified from only one data source (Reference 2), which presented data on two closed landfills. The site with the synthetic cap generated less leachate than the site with only a clay cap (130 versus 210 gal/ac-d). Other references did not specify if the landfill being studied was active or closed so further analysis would be difficult.

Reference 1: Richard J. Wigh, “Comparison of Leachate Characteristics from Selected Municipal Solid Waste Test Cells,” Project Summary. U.S. Environmental Protection Agency, September 1984. EPA-600/S2-84-124.

Data: Four test cells had measurement data, giving L/S ratio directly (L/S: annual leachate generation [L/yr] divided by mass of dry waste in landfill [kg]). The tests were conducted in Boone County KY, Sonoma County CA, and Cincinnati OH using municipal solid waste.

Cell 1 (KY): L/S=0.57/yr, mass of refuse=286,000 kg, maximum depth of 2.56 m

Cell 2 (CA): L/S=1.91/yr, mass of refuse=352,000 kg, maximum depth of 2.62 m

Cell 3 (KY): L/S=0.58/yr, mass of refuse=2,113 kg, maximum depth of 2.56 m

Cell 4 (OH): L/S=0.99/yr, mass of refuse=1,855 kg, maximum depth of 2.4 m

Precipitation: The average rainfall at the Kentucky and Ohio sites is 41 inches per year. The average rainfall at the California site is 30 inches per year.

Reference 2: Nancy Ragle, John Kissel, Jerry Ongerth, Foppe DeWalle. "Composition and Variability of Leachate from Recent and Aged Areas within a Municipal Landfill." Water Environment Research 67:238-242 (March/April 1995).

Data: Two sites had data, both from a MSW landfill near Seattle WA. One site was "old" and one was "new." At these sites the leachate generation rate and L/S ratio were calculated from the available data.

Old site: L/S= 0.0047/yr, L=1094 L/hr, area is 21.8 ha, mass of refuse 2.04×10^6 ton, unlined with clay/membrane cap. Leachate generation rate is 130 gal/ac-d.

New site: L/S= 0.0052/yr, L=3409 L/hr, area is 41.3 ha, mass of refuse 5.7×10^6 ton, synthetic liner and leachate collection system with clay cap. Leachate generation rate is 210 gal/ac-d.

Precipitation: The rainfall at the study location was reported as 54 inches per year.

Reference 3: Ole Johannsen and Dale Carson, "Characterization of Sanitary Landfill Leachates." Water Research 10:1129-1134 (1976).

Data: One site had data, a MSW landfill near Seattle WA, which may or may not be the same one identified in reference 2. The leachate generation rate and L/S ratio were calculated from the available data.

L/S=0.096/yr, L=20,000 m³/month, area is 120 ha, volume of refuse is 2.5×10^6 m³, maximum fill height is 15 m. Leachate generation rate is 590 gal/ac-d.

Precipitation: The rainfall at the study location was reported as 49 inches per year.

Reference 4: P. Baccini, G. Henseler, R. Figi, and H. Belevi, "Water and Element Balances of Municipal Solid Waste Landfills," Waste Management and Research 5:483-499 (1987).

Data: Several sites were investigated and leachate generation rates developed for MSW landfills. L/S ratios were approximately 0.025 to 0.05/yr (mass water per mass MSW). Leachate generation rates were not given.

Precipitation: Not presented.

Reference 5: James Lu, Bert Eichenberger, Robert Steams. Leachate from Municipal Landfills: Production and Management. Noyes Publications, Park Ridge NJ, 1985.

Data: Five MSW landfill sites were investigated; some of the landfills contained mixtures of industrial wastes (no more than 30 percent). Waste volumes, L/S ratios, and leachate generation rates had to be calculated from available data.

Site 1: L/S=0.0033/yr, refuse volume (est)= 3.09×10^6 yd³, average depth of 33 ft, 58 acre. Leachate generation rate is 100 gal/ac-d.

Site 2: L/S=0.0065/yr, refuse volume (est)= 0.81×10^6 yd³, average depth of 20 ft, 25 acre. Leachate generation rate is 120 gal/ac-d.

Site 3: L/S=0.034 to 0.073/yr, refuse volume (est)=32,000 yd³, average depth of 20 ft, 1 acre. Leachate generation rate is 620 gal/ac-d.

Site 4: L/S=0.0038 to 0.0092/yr, refuse volume (est)= 0.14×10^6 yd³, average depth of 8 ft, 11 acre. Leachate generation rate is 27 gal/ac-d.

Site 5: L/S=0.0041 to 0.017/yr, refuse volume (est)= 0.23×10^6 yd³, average depth of 20 ft, 7 acre. Leachate generation rate is 74 gal/ac-d.

Precipitation: Not presented.

Reference 6: "Management of Used Fluorescent Lamps: Preliminary Risk Assessment," Final Report. U.S. Environmental Protection Agency, May 14, 1993.

Data: Report presented data on waste input and leachate generation for an MSW landfill sampled by NUS in 1987 and four Wisconsin MSW landfills reported in Gordon, et. al., 1984. L/S ratios were calculated from these data. Data on areas were not presented, so normalized leachate generation could not be calculated.

SM Landfill: L/S=0.059/yr , mass of refuse=536,350,000 kg

Brown Co. E. Landfill: L/S=0.019, mass of refuse=93,294,000 kg

Eau Claire Co. Landfill: L/S=0.055, mass of refuse=56,599,000 kg

Marathon Co. Landfill: L/S=0.026, mass of refuse=93,122,000 kg

Delafield Landfill: L/S=0.0097, mass of refuse=82,766,000 kg

Precipitation: Not presented.

APPENDIX D. L/S RATIOS AND LEACHATE GENERATION RATES CALCULATED FROM CASE STUDIES

Data Summary: SAIC is assembling case studies for landfills using data from states, previous EPA studies, etc. In some cases, these case studies include the data elements discussed in Appendix A: (1) total quantity of leachate generated in a period of time (e.g., annually), (2) landfill area, and (3) waste volume or average depth. These data were used to calculate L/S ratios or leachate generation rates for the site.

A total of eight sites were identified in which sufficient data were available to characterize leachate generation rate, L/S ratio, or both. Unlike the data from Appendix A, these sites are predominantly non-MSW landfills. These data serve as a way to compare the Office of Water data to “actual” cases. Additionally, they provide a way to identify trends in the data. Trends observed from these data sources are as follows:

- Leachate generation was monitored at a single site over a period of 10+ years, from prior to cap placement to following cap placement. A noticeable drop in leachate generation rate was observed. L/S ratio necessarily decreases as well.
- The two sites with the highest L/S ratios (0.15/yr from the Radford VA site and the Chillicthe OH site) have very different landfill volumes: 300,000 and 34,000 yd³. This is useful in comparing to the Appendix A finding that high L/S ratios were found only in very small landfills. This finding may help to identify that a “high” L/S ratio would be over 0.15/yr.

Case Study Name	Waste and Landfill Characteristics	Waste Volume and Leachate Generation Rate	Calculated L/S Ratio, 1/yr	Calculated Leachate Generation Rate, gal/ac-d	Reference
Western Berks, Berks County PA	Closed and capped (PVC/clay) hazardous waste cell	Waste: 104,800 yd ³ Area: 2.3 acres Leachate prior to cap (4-year avg): 1.7 x10 ⁶ gallons/yr Leachate following cap (7-yr avg): 260,000 gallons/yr	prior to cap: 0.080 after cap: 0.012	prior to cap: 2,100 after cap: 320	Pre-petition to Delist Hazardous Waste Leachate Generated from Site A-1-3 at the Western Berks Refuse Authority, November 1997 (submitted to EPA Region 3).
Gum Springs Landfill	K088 monofill	Waste: 78,734 tons/yr (4-year average, range from 970 to 187,592 tons/yr) Area: Not available Leachate: 2,005,700 gal/yr (4-year average, range from 1,151,623 to 5,191,567 gal/yr)	average 0.11 (range from 0.0 to 0.15)	---	Reynolds Gum Springs Landfill K088 study, Attachment II, 5/29/97

Case Study Name	Waste and Landfill Characteristics	Waste Volume and Leachate Generation Rate	Calculated L/S Ratio, 1/yr	Calculated Leachate Generation Rate, gal/ac-d	Reference
EPA Report, "Site 13" unspecified location	Closed and capped hazardous waste cell	Waste: 88,600 MT Area: Not available Leachate: 18,000 to 28,000 L/yr (?)	0.0003	---	"Composition of Leachates from Actual Hazardous Waste Sites", SAIC, c. 1986.
Ingles Mountain Debris Landfill, Radford VA	Active C&D landfill	Waste: about 34,000 yd ³ Area: 3.25 acres Leachate: 1 x10 ⁶ gallons/yr	0.15	880	Office Of Water Docket for the Landfill Point Source Category (W-97-17), Presampling Site Visit Report
Modern Landfill, York PA	Active MSW Landfill	Waste: total quantity not available. Area: 167 acres Leachate: 1.2 to 2.4 x10 ⁶ gallons/yr	---	39	Office Of Water Docket for the Landfill Point Source Category (W-97-17), Presampling Site Visit Report
Frey Farm Landfill, Lancaster PA	Active MWC ash cell	Waste: About 400,000 ton Area: 6 acres Leachate: 420,000 gallons/yr	0.005	200	Office Of Water Docket for the Landfill Point Source Category (W-97-17), Presampling Site Visit Report
Mead Paper Depot Landfill, Chillicothe, OH	Closed industrial waste landfill (pulp sludge and fly ash)	Waste: 300,000 yd ³ Area: Not available Leachate: 8.8 x10 ⁶ gallons/yr	0.15	---	Office Of Water Docket for the Landfill Point Source Category (W-97-17), Presampling Site Visit Report
Mormon Hollow Road Demolition Landfill, Wendell MA	C&D waste landfill with both active and capped cells	Waste: Not available Area: 8 acre Leachate: 960,000 gallons/yr	---	340	Office Of Water Docket for the Landfill Point Source Category (W-97-17), Presampling Site Visit Report
Turnkey Recycling and Environmental Enterprises, Gonic NH	MSW/C&D Landfill with both active and capped cells	Waste: Not available Area: 46 acres closed, 50 acres active Leachate: 1.8 x10 ⁶ gallons/yr from closed section, 5.5 x10 ⁶ gallons/yr from active section	---	closed: 110 active: 310	Office Of Water Docket for the Landfill Point Source Category (W-97-17), Presampling Site Visit Report

APPENDIX E. LEACHATE QUANTITY DATABASE

Source: Effluent Guidelines for Landfills Point Source Category 308 Questionnaire

Data Dictionary

The primary data used in this analysis consist of information extracted from responses to an Office of Water survey. The paragraphs below identify and explain the specific data elements used. Where appropriate, the specific survey question number from which the data were extracted is identified. A table presentation of the data follows the dictionary.

Precip_Cat	A category assigned based on the precipitation reported in Question A.59 (see “Precip”, below), where 1 indicates less than 40 inches/year, 2 indicates 40 to 60 inches/year, and 3 indicates 60 or more inches/year.
SURVEYID	An identification code assigned to individual survey responses.
SUBCAT	Indicates the type of landfill: municipal ,Subtitle D (non-MSW), or hazardous waste.
Unit_No	A number indicating the specific landfill being described when a survey response covers more than one landfill.
Leach_Vol_Active	The average leachate production rate for the active landfill area in gallons/acre-day during the operating periods between 1988 and 1992 (Question A.52).
Leach_Vol_Inactive	The average leachate production rate for the inactive or closed landfill areas in gallons/acre-day during the operating periods between 1988 and 1992 (Question A.53).
Precip	The average annual precipitation during 1988 through 1992 (Question A.59).
LS_Ratio_BODF	The liquid to solid ratio calculated based on average daily flow and past waste inflows to the unit.
Stream_No	An identification number assigned to each wastewater stream generated by activity associated with the landfill (Table A-1). Information about wastewater streams identified as landfill leachate (see below) was extracted and used in this analysis.

Source	A code identifying the source of the wastewater stream. The first two characters identify the landfill number (see “Unit_No”, above). The final two characters identify the source type. Only wastewater streams with the final two characters “2L”, indicating landfill leachate, were used for this analysis (Table A-1).
Daily_Min_Flow	The minimum daily flow of landfill leachate in 1992 in gallons (Table A-1).
Daily_Max_Flow	The maximum daily flow of landfill leachate in 1992 in gallons (Table A-1).
Daily_Ave_Flow	The average daily flow of landfill leachate in 1992 in gallons (Table A-1).
Estimated	Indicates whether the data provided in the previous three data elements are based on actual measurements (“A”) or estimates (“E”) (Table A-1).
No_Cells	The total number of cells included in the landfill (Question A.30.a).
No_Cells_Active	The number of active cells included in the landfill (Question A.30.b).
No_Cells_Inactive	The number of inactive cells included in the landfill (Question A.30.c).
Past_Waste_Volume	The total volume of waste landfilled (Question A.32, total row).
Future_Waste_Volume	The total future landfill capacity (Question A.32, total row).
Waste_Units	A code indicating the units in which the previous two data elements are expressed (e.g., “CYD” indicates cubic yards) (Question A.32).
Length	The typical cell length (Question A.37.a).
Width	The typical cell width (Question A.37.a).
Dim_Units	A code indicating the units in which the previous two data elements are expressed (e.g., “FET” indicates feet) (Question A.37.a).
Depth	The typical cell depth (Question A.37.b).

Dep_Units	A code indicating the units in which the previous data element is expressed (e.g., “FET” indicates feet) (Question A.37.b).
Total_Area	The total area of the landfill, based on “Length,” “Width,” and “Depth,” above.

APPENDIX F. QUALITY ASSURANCE ANALYSIS AND ADJUSTMENT OF STATE OF WISCONSIN LEACHATE CHARACTERIZATION DATA

Among the data collected for inclusion in the LEACH 2000 database was a data set from the State of Wisconsin Department of Natural Resources (DNR) with characterization data for approximately 70 landfills. In examining this data set, certain patterns of statistical outliers were discovered. These patterns were consistent with intermittent misreporting of analytical units. Wisconsin DNR staff was contacted about this possible explanation for the outliers. The DNR staff agreed that the data points did appear questionable (and, in some cases, physically impossible) and that misreporting of analytical units at the laboratory or reporting facility level was a possible explanation. The DNR, however, did not have sufficient resources to investigate the data points in question and verify that misreporting had occurred.

So that the Wisconsin data set could be incorporated into the LEACH 2000 database as accurately as possible, a detailed analysis was undertaken to identify and correct data points suspected of having a problem with reporting of analytical units. This appendix describes the procedures used in and adjustments made as a result of this analysis. Two related misreporting problems were suspected in the Wisconsin data. These problems were addressed using the techniques below, identified as "Approach 1" and "Approach 2." The Wisconsin data set adjusted as a result of these approaches is contained in the "Source_WI_New" and "Leach Combined" tables of the LEACH 2000 database. The original Wisconsin data set, unadjusted by either Approach 1 or 2 has been maintained in the database in the table "Source_WI."

Approach 1

One suspected problem was a pattern of data points reported as being in milligrams per liter (mg/L) that appeared to actually be in micrograms per liter ($\mu\text{g/L}$). This problem resulted in data points that were not only questionably high, but physically impossible (e.g., magnesium levels of greater than 1,000,000 mg/L, which would correspond to concentrations greater than 100 percent). This problem appeared to effect every data point that was originally reported in the Wisconsin data set to be in mg/L. A possible explanation for this pervasive problem would be if all of the data originally recorded in mg/L were converted to $\mu\text{g/L}$ without changing the field identifying the analytical units.

To add confidence that this problem was the result of consistent misreporting, summary statistics were generated for all constituents that were reported in mg/L in the Wisconsin data set. For nearly all these constituents, the Wisconsin data set included at least one observation that appeared to be a physical impossibility (e.g., concentration in excess of 100 percent). The Wisconsin summary statistics for these constituents also were compared to summary statistics for the same constituents from all other data sources included in the LEACH 2000 database. In all cases, the Wisconsin data had maxima, means, and minima that were approximately three orders of magnitude greater than the corresponding statistics from the other data sources. This result was taken as sufficient evidence that a pervasive misreporting problem had occurred for all data points originally identified as in mg/L. All of these data points, therefore, were divided by 1,000

to convert them to the correct units. This conversion resulted in summary statistics much more similar to those from the other data sources, as shown for a sample constituent in Table F-1, below. Table F-2 lists all of the constituents that were converted in this manner.

Table F-1. Effect of Adjustments Using Approach 1: Summary Statistics for Alkalinity from Various Data Sources (mg/L)

Data Source	Minimum	Mean	Maximum
Original Wisconsin Data Set	1,260	2,602,000	44,400,000
Converted Wisconsin Data Set	1.26	2,602	44,400
All Other Data Sets	1.00	3,621	110,000

Table F-2. Constituents in Wisconsin Data Set Adjusted Using Approach 1

ALKALINITY, BICARBONATE (MG/L AS CaCO ₃)	MAGNESIUM, DISSOLVED (MG/L MG)
ALKALINITY, CARBONATE (MG/L AS CaCO ₃)	MAGNESIUM, TOTAL (MG/L MG)
ALKALINITY, TOTAL (MG/L AS CaCO ₃)	MOLYBDENUM, TOTAL (MG/L MO)
ALKALINITY, TOTAL FILTERED (MG/L AS CaCO ₃)	NITRATE NITROGEN, DISSOLVED (MG/L AS N)
AMMONIA, UNIONIZED PERCENT OF TOT. T-PH CAL (MG/L)	NITRATE NITROGEN, TOTAL (MG/L AS N)
BIOCHEMICAL OXYGEN DEMAND (MG/L, 5 DAY - 20DEG C)	NITRITE NITROGEN, DISSOLVED (MG/L AS N)
BIOCHEMICAL OXYGEN DEMAND (MG/L, 6 DAY - 20DEG C)	NITRITE NITROGEN, TOTAL (MG/L AS N)
BIOCHEMICAL OXYGEN DEMAND, (MG/L, 5 DAY DISSOLVED)	NITRITE PLUS NITRATE, DIS. 1 DET. (MG/L AS N)
BORON, DISSOLVED (MG/L B)	NITRITE PLUS NITRATE, TOTAL 1 DET. (MG/L AS N)
BORON, TOTAL (MG/L B)	NITROGEN, AMMONIA, DISSOLVED (MG/L AS N)
CALCIUM, DISSOLVED (MG/L CA)	NITROGEN, AMMONIA, TOTAL (MG/L AS N)
CALCIUM, TOTAL (MG/L CA)	NITROGEN, KJELDAHL, DISSOLVED (MG/L AS N)
CARBON, TOTAL ORGANIC (TOC) (MG/L AS C)	NITROGEN, KJELDAHL, TOTAL (MG/L AS N)
CARBONATE ION (MG/L CO ₃)	NITROGEN, ORGANIC, TOTAL (MG/L AS N)
CHEMICAL OXYGEN DEMAND, FILTERED (MG/L)	OIL & GREASE (FREON EXTR-GRAV METH) TOT REC (MG/L)
CHEMICAL OXYGEN DEMAND, UNFILTERED (MG/L)	PHOSPHATE, TOTAL (MG/L AS PO ₄)
CHLORIDE, TOTAL OR DISSOLVED IN WTR SMPL (MG/L CL)	PHOSPHORUS, TOTAL (MG/L P)
CYANIDE, TOTAL (MG/L CN)	POTASSIUM, DISSOLVED (MG/L K)
FLUORIDE, DISSOLVED (MG/L F)	POTASSIUM, TOTAL (MG/L K)
FLUORIDE, TOTAL (MG/L F)	SODIUM, DISSOLVED (MG/L NA)
FORMALDEHYDE (MG/L)	SODIUM, TOTAL (MG/L NA)
HARDNESS, CALCIUM (CA) (MG/L AS CaCO ₃)	SOLIDS, TOTAL (MG/L)
HARDNESS, MAGNESIUM (MG) (MG/L AS CaCO ₃)	SOLIDS, TOTAL DISSOLVED (MG/L)
HARDNESS, TOTAL (MG/L AS CaCO ₃)	SOLIDS, TOTAL SUSPENDED (MG/L)
HARDNESS, TOTAL, FILTERED (MG/L AS CaCO ₃)	SULFATE, DISSOLVED (MG/L SO ₄)
IRON, DISSOLVED (MG/L FE)	SULFATE, TOTAL (MG/L SO ₄)
IRON, TOTAL (MG/L FE)	SULFIDE, DISSOLVED (MG/L S)
	SULFIDE, TOTAL (MG/L S)
	SULFITE (MG/L SO ₃)
	TANNIN AND LIGNIN, COMBINED (MG/L)

Approach 2

The other suspected misreporting problem in the Wisconsin data set did not appear in a similar consistent pattern. Certain individual data points, or series of data points taken from a period of dates, were approximately three orders of magnitude lower than other data points for the same constituent at the same landfill. For some parameters, this degree of variation alone might not be sufficient to suspect a reporting problem (i.e., the variation could be due to legitimate, natural changes in leachate concentration). For many of these data points, however, the reported concentrations also were several orders of magnitude below typical analytical detection limits (e.g., lead concentrations in the range of 0.01 µg/L).

These questionable data points did not occur in obvious patterns. That is, they were not limited to a few landfills or a particular period in time. When these suspiciously low data points occurred at a given landfill during a given time period, however, they appeared to occur across constituents. For example, frequently, at landfill “x” on date “y” all metals concentrations would be three orders of magnitude lower than their previous or subsequent concentrations. A possible explanation for this phenomenon would be if a group of analytical results actually measured in mg/L were inadvertently misreported as being in µg/L. This problem could occur intermittently at different reporting facilities at different points in time.

In part because no clear pattern existed to these questionable data points, no one method would be sufficient to detect and correct them. To detect where this misreporting problem might occur, a series of statistical and rational criteria were established. All of the Wisconsin data were evaluated according to the following criteria:

1. Statistical outlier with respect to the full data set: data points met this criterion if they were determined to be outliers based on a statistical test (Tukey’s method as found in Tukey, “Exploratory Data Analysis,” 1977, pp 42-44) that compared them to the full set of LEACH 2000 data from all data sources¹ for that constituent.
2. Reported concentration lower than typical analytical detection limits: data points met this criterion if they were more than an order of magnitude below reasonable analytical detection limits. Because detection limits can vary from lab to lab, the detection limits used for this test were Practical Quantitation Limits (PQLs) for ground-water monitoring as reported in 40 CFR 264, Appendix IX. For constituents with no PQL in Appendix IX, the “typical” detection limit was assumed to be the median detection limit reported for all observations for that constituent in the LEACH 2000 database.
3. Outside control limits specific to the facility and constituent: data points met this criterion if their moving average with the previous or subsequent data point fell outside statistical

¹ Excluding data from the EPA Office of Water, which was not available at the time this test was performed.

control limits established (using the method described in Gilbert, “Statistical Methods for Environmental Pollution Monitoring,” 1987, pp.193-200) for the full series of data for that constituent at that landfill.

4. Detection limit lower than typical analytical detection limits: a data point met this criterion if a detection limit was reported and was more than an order of magnitude below the typical detection limits described in criterion (2), above.
5. Correlated with other questionable data points: a data point met this criterion if it occurred on the same date as another data point meeting criterion (1) or (2), above.

Criterion (1) and criterion (2) were considered the “major” criteria. It was considered sufficient evidence that a units misreporting problem was present if a data point met one of the major criterion and any other criterion, major or minor. It also was considered sufficient evidence that a units misreporting problem was present if a data point met all three of the minor criteria. When these conditions were met, concentrations were adjusted by three orders of magnitude (either up or down, depending on whether they were high or low outliers). Data points were not adjusted, however, if this adjustment would result in an outlier problem at the other end of the distribution. For example, if multiplying a seemingly low concentration by 1,000 would result in a concentration that would be a high outlier by criterion (1), the data point was not adjusted.

A total of 920 observations were adjusted as a result of Approach 2. These data points are identified in the LEACH 2000 database with a “1” in the “QA Adjusted?” field of the “Source_WI_New” table. Table F-3, below, shows the effect of these adjustments for an example constituent.

Table F-3. Effect of Adjustments Using Approach 2: Summary Statistics for Lead before and After Conversion

Data Source	PQL	Minimum	Percent of Obs. <0.1 µg/L	Percent of Obs. <1 µg/L	Percent of Obs. <10 µg/L
Original Wisconsin Data Set	10 µg/L	0.0018 µg/L	9%	13%	47%
Converted Wisconsin Data Set		0.18 µg/L	0%	0.2%	37%